SUPPLEMENT

TO THE

FORTY-THIRD ANNUAL REPORT OF THE DEPARTMENT OF MARINE AND FISHERIES FOR THE FISCAL YEAR 1909-10.

REPORT ON ICE FORMATION

IN

THE ST. LAWRENCE RIVER

AND

A REPORT ON THE INFLUENCE OF ICEBERGS ON THE TEMPERATURE OF THE SEA AS SHOWN BY THE USE OF THE MICRO-THERMOMETER IN A TRIP TO HUDSON STRAIT AND BAY IN JULY, 1910

BY

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1911

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ICE FORMATION ON THE ST. LAWRENCE.

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To Mr. Geo. J. Desbarats,
Deputy Minister of Marine and Fisheries.

Sir,—I have the honour to submit the following report, with my compliments.

H. T. BARNES.

Again through the kind assistance of the Department of Marine and Fisheries, I have been able to extend my studies of ice phenomena and to examine in more detail certain interesting questions which arose during the work of last year. It is a pleasure to record great indebtedness to the minister, Hon. L. P. Brodeur, for his readiness to extend assistance to scientific work like the present, and his keen interest always shown in the outcome of the work. To the deputy minister, Mr. G. J. Desbarats, the writer desires to express his warmest thanks not only for the ready help accorded him on all occasions, but for that unfailing interest and helpful advice which assisted so much the success and progress of the investigations. As in the previous work, the department generously provided me with an assistant, Mr. Louis Vessot King, B.A., who devoted four months to a close study of ice conditions from the deck of the Canadian Government steamers *Lady Grey* and *Montcalm*. I cannot speak too highly of Mr. King's work, and of the great assistance he has been to me in this investigation. Much of the work attempted would have been impossible but for the association of so able a man.

Ice conditions were studied at Cap Rouge during the winter, and an excellent opportunity was afforded for studying the disintegration of ice at Lake St. Peter. A trip to the Northumberland straits enabled observations to be made on the new ice breaker, *Earl Grey*, which has done such excellent service this year between Pictou and Charlottetown, P.E.I. Three weeks in April spent on the *Lady Grey* at Crane island completed the winter's work.

There are certain features in connection with the suggestions made in the report of last year which have been well verified during the past winter. The use of two ice breakers at Cap Rouge has resulted in an entire absence of any ice jam permanently setting in at Cap Rouge. At no time were the ice breakers severely taxed. It was an easy task for the boats to keep the channel clear, with the result that the tide and currents had their full effect on the river above, giving open water all the way to Three Rivers.

No more marked demonstration of the efficiency and ease of preventative measures in dealing with ice conditions could be cited than the work of the boats this year. As I pointed out last year, 'It is but the work of a few days or less for the formation of the famous bridge at Cap Rouge, and yet it is the work of two months to break it down again, whereas the presence of an ice breaker during the first few days and after would prevent the bridge from forming altogether, and make the task of keeping the river clear at that point a simple one.' Further on I state, 'There seems to be little reason why one or two powerful ice breakers should not be able to keep the river clear from Quebec to Lake St. Peter at least. One difficulty might be encountered in the masses of frazil that would be formed in the open water.' This year the two ice breakers had no difficulty in keeping the river clear to Three Rivers by merely working at Cap Rouge. One of the most important discoveries made this year is the effect of open water on the water temperature in winter. I suggested last year that frazil ice would be produced in larger quantities. At no time, however, was frazil troublesome, and for the entire winter the temperature of the water at Quebec was higher than freezing owing to the effect of the sun on the open water above. The whole effect of surface ice on the temperature of large masses of water is presented in a new light when considered with reference to the absorption of the sun's heat. I am convinced that the task at Quebec was rendered much easier owing to the presence of open water above. My whole fear had been that open water would have acted in quite a different way. Mr. King devoted a great deal of time to studying the effect of the sun on the temperature of the water, and some important meteorological results are likely to arise from these observations.

This report which I have the honour to submit is divided into the following sections:—

Section I.—General meteorological conditions and extracts from the reports submitted by Mr. King on the ice conditions existing during the winter.

Section II.—Measurements of water temperatures to a thousandth part of a degree by means of a new marine thermometer.

Section III.—Effect of the sun on the general ice conditions. The absorption of the solar heat by the water.

Section IV.—The influence of ice on the temperature of the water.

Section V.—The rate of growth of surface ice.

Section VI.—Some problems affecting the maintenance of an open channel between Montreal and Quebec during the winter.

SECTION I.

General meteorological conditions, and extracts from reports submitted by Mr. King on the ice conditions existing during the winter.

The winter of 1909-10 was a mild one, so far as the meteorological records show, all the months except February being above the average. February was, however, below the average. The temperature during the month of March departed to the greatest extent from the mean, being some eight degrees warmer. A strong sun, with fine mild weather, assisted very much the early disintegration of the river ice. In some respects extremes of temperature following one another make the ice problem harder to cope with. The cold weather forms the ice, which always grows faster in its initial stages, and the warm weather brings it down the river in large quantities, making the danger of a jam at Cap Rouge more likely. When the cold weather persists the battures remain in place, and merely increase in thickness. The total growth of ice under such circumstances is, I believe, actually less than when the mild weather dislodges the battures and the next cold snap forms them again.

EXTRACTS FROM MR. KING'S REPORTS.

December 20, 1909 (Monday).—Arrived at Quebec, and took up quarters on board the government ice breaker, *Lady Grey*. The steamer had been out between high tide at noon and 3.30 p.m., going as far as Pte. aux Trembles. Light open ice was met with (4 to 6 inches thick).

December 21, 1909 (Tuesday).—Moderate snowfall during the day. Wind N.W. The *Lady Grey* left her dock about 1 p.m. with the high tide. Light open ice, somewhat heavier than the preceding day was met with. The ice was for the most part in large sheets about eight inches thick and often several hundred feet across. This ice was very brittle and gave way before the *Lady Grey* with a sharp crackling sound. The waves caused by the steamer were sufficient to break up the ice for about 60 feet on either side of the steamer. There were, especially below and above the Quebec bridge, large spaces of open water; these were often partially covered over with thin 'lolly-ice,' soft, flakey and easily disintegrated. This ice forms very rapidly, especially on windy days, a piece as large as a man's fist growing to a couple of feet in diameter in the space of two or three hours. This kind of ice was observed to form and extend out from the windward side of the fine cakes, and is no doubt responsible for cementing these together. In the narrow portion of the river opposite the Quebec bridge the open spaces of water had disappeared; the ice was very rough, and presented the appearance of small cakes piled up on one another and frozen together. This was no doubt due to the crumpling up of the ice floes in the narrow gorge. Above this

point as far as St. Nicholas the ice became more open. Apparently there is no danger of a jam at Cap Rouge with the thin ice prevailing at present. The crucial time is at a period of high tides. If up to this time cold weather has prevailed, the large ice fields of from two to three feet in thickness form in the wide and shallow bays in the river near Pte. aux Trembles, about 10 miles above Cap Rouge. Here the river widens to four miles, and is often not more than six feet deep. A very high tide and a N. to N.E. wind will dislodge enormous floes which come down the river with the ebb tide in very large solid pans. Some of these pans are large enough to reach right across the river at Cap Rouge, and if the ice is strong enough to resist being broken up it remains jammed from shore to shore and starts the ice bridge. Ice coming from above is caught by this bridge, some is carried underneath the floe, some piled on top, the whole is cemented together with frazil and very soon the bridge becomes a solid mass of ice, 15 to 20 feet thick. It is not likely that any bridge would form were it not for the initial bridge formed by the large, solid pans coming from the shallows of Pte. aux Trembles. The water is too shallow for the *Montcalm* or the *Lady Grey* to break up those large pans as they form over the shallow water; a fleet of small tugs, escorted by one of the large boats, might do good work in keeping the ice broken up here. Three or four large piers sunk in the bay at this point would probably suffice to keep the large pans in place through periods of high tides and so throughout the whole winter. There would be no difficulty arising from large pans coming down from points higher up the river.

Use of tugs to assist.

At St. Nicholas the *Lady Grey* turned, arriving at Quebec at 4 p.m.

December 22, 1909 (Wednesday).—Snow during the night; sky overcast during the day. Air temp.: max., 26° F., min., 22° F. Humidity: max., 90 per cent, min., 81 per cent. The *Lady Grey* left her dock about 1 p.m., one hour before the turning of the tide. The increase in the humidity since yesterday was at once noticeable in the character of the ice: to-day the ice, which was encountered in large pans covered with snow, was very soft and gave way before the ice breaker with a dull, grating sound; often long cracks would open out in front of the steamer. Although the pans were for the most part no thicker than yesterday, the ice was much stickier, and in consequence offered considerably greater resistance to the ship. A number of large floes presented the appearance of broken ice loosely cemented together. Ice of this character is formed by the breaking up of the large pans in passing through the gorge at Cap Rouge either with the inward or ebbing tide. Several large masses of this type reached a thickness of three or four feet with loose ice underneath, and proved difficult to break up. A great deal of the ice formed in large pans showed mud and gravel on the underside, indicating that these had formed on shoals and were left stranded at low tide.

Effect of humidity on the ice.

A sample of water in an open space was examined, but no frazil crystals could be detected in it.

The *Lady Grey* turned just below Pte. aux Trembles, arriving at Quebec at 4 p.m.

December 23, 1909.—Overcast during the night; fine and clear during the morning, slightly cloudy and overcast in the afternoon. Air temp.: max., 28° F., min., 16° F. Humidity: max., 86 per cent, min., 70 per cent.

The *Lady Grey* left her dock at 1 p.m. about two hours before high tide. The ice was much lighter than yesterday, much more open, and owing to a N.W. wind was thickest on the south shore, the north shore being practically open water. The ice was somewhat more brittle than yesterday, and as far as the Quebec bridge presented much the same appearance. Above this point the ice was for the most part very thin (1 to ½ inch), and showed evidence of having formed in the quiet open spaces between the thicker floating pieces. Adhering to the underside of the pieces of heavier ice, especially such ice as was covered with snow, large spongy masses of frazil ice could be noticed; in fact several samples of water showed a number of frazil crystals (about 5 per C.C. on the average). Above St. Nicholas there seemed to be no heavy ice, most of the ice at this point being the thin recently formed ice already described. At this point the *Lady Grey* turned, arriving at Quebec at 3.30. A water temperature was taken on arriving in dock, the scale reading being 16. Water temperature was 1/100 of a degree of 0° C.

Frazil appears.

December 24, 1909.—Slightly overcast during the night. Clear and bright towards morning and during the forenoon. Air temp.: max., 18° F., min., 13° F. Humidity: max., 80 per cent, min., 66 per cent.

The *Lady Grey* left her dock with the last of the ebb tide at 7.15 a.m. The weather was perfectly bright and clear. The river was open as regards ice, which was more brittle than on the preceding day and was still inclined to accumulate on the south shore. The effect of the sharp frost during the night could be seen by the quantity of new, thin ice formed between the heavier cakes. Often the water in the open spaces was covered with a thin scum of ice-crystals on the point of forming thin surface ice. Several large areas of thin 'conglomerate ice' were met with. These are made up of round cakes of ice, a couple of feet in diameter, formed by the action of a moderate wind in breaking up and rounding up the corners of the thin surface ice. Frazil ice seemed to be forced up into ridges around the edges of the cakes. In many cases these fields were not frozen together rigidly, so that the waves caused by the ship could be seen travelling along them. In general such areas presented the appearance of the surface of a honeycomb.

Effect of humidity on the ice.

Conglomerate ice.

Samples of water were examined for frazil; crystals existed in greater number than yesterday (about 10 per c.c.). Often these crystals seemed gathered together in loose aggregates several cms. in diameter, exhibiting the initial stages of the formation of slush ice.

Frazil.

December 28, 1909.—Morning clear and bright. W. breeze.

The *Lady Grey* left dock with the high tide at 8 a.m. Up to Cap Rouge the ice was light and open, the larger pans being four to five inches thick. The morning was misty and the water steaming. Following the valley of the river and hanging almost down to the water, a line of cloud could be seen. At Cap Rouge the ice showed signs of congestion, and above that point several large masses of 'batture ice' were encountered; one of these bore a small fishing

Effect of Spring tides.

cabin. The spring tides prevailing at present were responsible for dislodging the 'battures' from the shoals between Pte. aux Trembles and Les Ecureuils. Several of these, had they been heavier after a prolonged spell of severe weather, would have been large enough to start the blocade at Cap Rouge. One of these 'battures' was estimated at 1½ miles in width and 2 miles long. In such cases a 'wireless' installation on board would have proved invaluable; the *Lady Grey* would have been enabled to communicate with the *Montcalm*, the two boats would thus be able to break up this 'batture ice' in time, and by so doing diminish the chances of the blockade commencing at Cap Rouge. In places the 'batture ice' was as much as six feet thick and conglomerate in composition, although not as yet very solid nor difficult to break up. The *Lady Grey* turned at St. Nicholas, and after breaking through the large battures without difficulty, arrived in dock about 11 a.m.

Need of Marconi for "Lady Grey."

Frazil.

Samples of water showed considerable quantities of frazil, about 20 crystals per c.c.

December 29, 1909.—Overcast during the night; fine and clear towards morning.

The *Lady Grey,* owing to some minor repairs, did not leave dock to-day, and the *Montcalm* performed the journey, leaving Quebec at 9 a.m. The ice was everywhere light and open, and very few 'battures' were encountered; mostly those which had been dislodged had already gone down beyond Cap Rouge.

The effect of the fairly severe weather prevailing at present could be seen in the fairly thick ice formed in large pans (6 to 8 inches). For the type of ice encountered to-day the *Lady Grey* is as effective as the *Montcalm,* and seems as easily able to force her way through the ice. This may be due to the fact that the *Montcalm* is not yet fitted with the high-pitch winter propellers necessary to obtain a good purchase on the water when forcing through the ice at a slow speed. Besides the engine valves are still cut down to economize strain, whilst still giving enough power for summer work. When the heavy ice begins to come down with the next spring tide it is essential that the *Montcalm* be in her most efficient working order, not only as regards propellers and engines but also in being able to command a high steam capacity, for which a better quality of coal than that being used at present is necessary. The *Montcalm* turned at St. Antoine and arrived in Quebec about noon.

Condition of "Montcalm."

No frazil.

December 30, 1909.—Night fine, clear and cold; morning clear and calm, becoming overcast towards noon. No frazil in the water.

The *Lady Grey* left her dock at 10 a.m. The ice proved to be fairly heavy in consequence of the extreme cold prevailing at present. However, batture ice was entirely absent. Most of the open spaces of water were covered with thin ice (about ½ inch); nevertheless over these spaces there was a low-lying mist. Above Cap Rouge the ice seemed more open. Large pans of thin ice (4 to 6 inches) stretching almost from shore to shore were encountered. About a mile above St. Nicholas the ice seemed to reach from shore to shore, and showed signs of forming a bridge at this point. The large fields just mentioned were probably just broken off by the high tide. These had formed during the 24 hours since the *Montcalm* had passed yesterday, and gives an idea of the rate at which ice forms in cold weather.

Mist over the ice.

About noon samples of water were examined; no crystals, in spite of the extreme cold, could be detected. The *Lady Grey* after turning a mile above St. Nicholas arrived in dock about 1 p.m. No frazil.

December 31, 1909.—Night fine and clear; morning and afternoon partly overcast; very slight snow flurry; calm.

Frazil—1 sample, none; 3 samples, plentiful, about 30 crystals per c.c. Frazil.

The *Lady Grey* left dock at 12 noon. Although the ice proved light and open below Cap Rouge, at this point it seemed to be massed in large quantities. A great deal of it was very rough and was made up of blocks piled up on each other to a thickness of 4 or 5 feet with frazil slush underneath. This type of ice, although not solid, is very hard to get through and offers great resistance to the ship. Nevertheless the *Lady Grey* was able to get through it at a rate of about three miles an hour. Above the Quebec bridge and as far as St. Nicholas, numerous large fields of sheet ice (about 4 to 6 inches thick) were encountered. These often reached from shore to shore, and there was little open water visible. Large numbers of frazil crystals were found in the water. At St. Nicholas the *Lady Grey* turned, and arrived in Quebec about 4 p.m. Frazil.

January 1, 1910.—Night and day overcast; light snow falling. Slight E. breeze. Frazil fairly plentiful—15 crystals per c.c. Frazil.

The *Lady Grey* left dock at 1 p.m. Very light ice was everywhere encountered; one or two battures were seen, one bearing down three fishing cabins. These battures were very thin, and had been dislodged by the mild weather prevailing at present. A large number of globular sponge-like masses of ice were met with. These floated very low in the water, and were brown in colour due to the quantities of mud contained in them. These masses constitute a type of 'anchor ice,' and are said to form over mud flats by the action of cold weather and wind at low tide. Above the Quebec bridge the ice was met with in large pans, but was very thin (2 to 3 inches). The *Lady Grey* turned at St. Nicholas, and arrived in Quebec at 4 p.m. Anchor ice.

January 2, 1910.—Morning overcast; light snow flurries. Day clear and mild; moderate W. wind.

The *Montcalm* left dock at 1.23 p.m. Very light ice was encountered. Owing to a W. wind it tended to crowd into the south shore. Above the Quebec bridge a large piece of 'batture ice,' about 1½ miles long and two or three hundred feet in width, was encountered. This batture was broken up into fragments both in going up the river and in returning. The batture was 4 or 5 feet thick, and was heavy enough to almost stop the ship's way. The *Montcalm* turned just below St. Nicholas, and arrived in dock at 3.45 p.m.

January 3, 1910.—Night fair and clear, becoming overcast towards morning, with considerable snow falling in the afternoon; slight E. breeze. Frazil crystals, 15 per c.c. Water temperature in dock, 32° F. Air temp.: max., 12° F., min., 8° F. Frazil.

The *Lady Grey* left dock at 1 p.m. Open ice was everywhere encountered, with a few pieces of batture ice. The open spaces of water were everywhere covered by a thin scum of ice caused by the falling snow. Above the Quebec bridge the ice was very open and thin. The effect of a day of mild weather is at once noticeable in the

Effect of mild weather on ice.

Frazil and slush.

quality of the ice met with during the next two or three days. Ice then forms very slowly, and that coming down, in consequence, very thin. Samples of water, besides containing a great deal of slush due to the falling snow, showed frazil crystals in considerable number. The *Lady Grey* turned at St. Nicholas, and arrived at Quebec at 3.45. Just opposite the Beauport shoal and extending almost from shore to shore, a large field of batture ice was noticed. This was broken up before proceeding into dock.

Frazil.

January 4, 1910.—Night overcast, with E. wind. Sudden fall of temperature towards morning, with a N.W. wind. Fine and clear during the day. Air temp.: max., 0° F., min., 13° F. Frazil plentiful, 40 crystals per c.c.

Frazil.

Effect of sudden cold on ice.

The *Lady Grey* left dock at 1 p.m. The sudden fall in temperature (10° F. to 13° F.) was responsible for the formation of large areas of thin ice. Comparatively few open spaces of water could be seen. Over these a strong W. wind was blowing, and frazil ice was forming very rapidly. (Samples showed about 40 large crystals per c.c.). The wind caused these to collect on the windward side of the ice sheets, where it first forms a thin scum and finally solidifies to the thin sheet ice. Most of the ice met with varied from 2 to 5 inches in thickness, and no heavy ice was encountered. The *Lady Grey* turned at St. Nicholas. The rapidity with which ice forms when the temperature is in the neighbourhood of 10° F. could be seen when on several occasions we crossed our original track on the return journey. Although not more than one-half to three-quarters of an hour had elapsed, the broken ice in the ship's wake had been cemented together by ice about ½ inch thick. On returning to dock about 3.30 an inch of ice had formed over the quiet water where the ship had been.

Effect of blizzard.

January 5, 1910.—Fine and very cold during the night; overcast towards morning; a heavy blizzard with a N.E. wind began at 1.15 p.m. Air temp.: max., 14° F., min., —14° F.

The *Montcalm* left dock at 1 p.m. The ice in the river opposite Quebec was open and moving, although fairly heavy in consequence of the extreme cold. On leaving, the weather was calm although the sky was somewhat overcast. At 1.15 p.m. snow began to fall and in five minutes a blizzard was raging, and all sight of the shore and landmarks was immediately blotted from view. It was impossible to proceed further, so at 1.20 p.m. the *Montcalm* turned, and arrived in dock at 1.50 p.m., steering by compass on the way in.

Slush and anchor ice.

January 6, 1910.—Night overcast, with snow falling. Snow ceased towards midnight, and the temperature rapidly became milder towards morning. Wind W.; morning overcast and humidity high. Water contained traces of slush, but no true frazil crystals. Anchor ice.

Effect of humidity.

Anchor ice.

The *Lady Grey* left dock at 7.15 a.m. The ice was open as far as the Quebec bridge, although somewhat heavy in consequence of the extreme cold which prevailed during the last two or three days. The effect of the sudden rise in temperature and humidity was noticeable in the fact that the ice was not so brittle as usual and in the quantities of anchor ice to be seen. Above the Quebec bridge the river was not so open. Large fields of ice (4 to 6 inches thick) covered the

river from shore to shore. These, however, were moving downwards with the ebb tide, although not so fast as the tide itself. In this case long strips parallel to the free edge break off on the down-stream side of the field and are carried down by the tide with greater rapidity. Samples of water showed no traces of the needle-shaped frazil crystals, although traces of slush, probably half melted snow crystals, were present.

Effect of ebb tide.

Slush, no frazil.

January 12, 1910.—Night overcast; light snow flurry during the morning; afternoon clear; calm. Traces of frazil. Air temp.: max., 18° F., min., 5° F.

The *Lady Grey* left dock at 7.45 a.m. with the high tide. As far as the Quebec bridge and in the open river beyond the ice was light and open. An hour was spent cutting away the 'batture ice,' which forms between the north pier of the bridge and the Cap Rouge river. As soon as this batture has grown to a certain width it increases very rapidly, owing to the fact that the channel is considerably narrowed and the floating ice is crowded up against the batture with great force by the set of the current at this part of the river. Since January 10 the batture has grown out about 200 feet, so that 50 feet may be added during a single tide. The addition of each tide is marked off from that of the preceding tide by a well marked ridge running along the batture parallel to its edge. The ice between these ridges consists of piled-up blocks, which have the characteristic thickness of the ice prevailing at the time this part of the batture was formed, and so the whole batture gives an indication of the severity of the weather which has prevailed day by day during its formation. In order to cut away the batture, it was necessary to resort to 'bucking,' i.e., to charge into the ice at full speed. Best results are obtained by working in the direction of the tide. The batture cracks most easily along the tide-ridges already mentioned; as soon as a crack opens out large quantities of small broken ice and slush rise to the surface. Progress is at first slow, but very soon the whole batture becomes rapidly weakened by the repeated charges, by the wash of the ship and by the suction of the propellers, with the result that before very long large pieces can be easily disengaged from the main mass. As the result of an hour's work, a long strip of batture about a mile long and five or six hundred feet wide was cut away without difficulty.

Forming of a batture.

Cutting a batture.

The *Lady Grey* then proceeded as far as St. Nicholas church. The ice was everywhere thin, and no 'battures' could be seen coming down the river from above. After stopping to take on a supply of fresh water at the Government wharf, the *Lady Grey* arrived in dock about noon.

January 15, 1910.—Night fine and clear; the day clear and bright; calm, with a westerly breeze towards the afternoon. Air temp.: max., 16° F., min., —10° F.

The *Montcalm* left dock at 10.30 a.m. The ice was everywhere light and open, and of no very great thickness (3 to 5 inches) except as regards the large pans which had been squeezed through the Cap Rouge gorge. The *Montcalm* proceeded as far as the St. Croix light; the ice opposite Pte. aux Trembles was light, and the battures had not as yet attained any very great width. It was noticeable that the large sheets of surface ice became thinner as the *Montcalm* proceeded up the river. No battures were met with coming down with the tide;

such as have formed seem to be too solid to be dislodged by the high tides. The *Montcalm* arrived in Quebec at 3 p.m.

Frazil

January 16, 1910.—Night fine and clear; morning fine and clear, becoming slightly overcast towards evening. Barometer, 30.95. Frazil—no small crystals, a few large ones. Air temp.: max., 16° F., min., 0° F.

The *Lady Grey* left dock at 1 p.m. Up to the Quebec bridge the ice was remarkably open. In the Cap Rouge gorge there was a great deal of thin ice (3 to 4 inches) squeezing through with the strong tide. Up to St. Nicholas the ice consisted of large sheets of thin ice (3 to 4 inches). No battures were met with. The *Lady Grey* turned at St. Nicholas, and arrived in dock about 4 p.m.

Frazil formation described.

Distinction has several times been made between 'small' and 'large' frazil crystals. The small crystals (about ½ inch long) seem to occur only when the weather is very cold (below zero), and even then none may sometimes be found when the weather is clear. The small crystals are needle-shaped, have small buoyancy and seem to be uniformly distributed throughout the water of the river. The large crystals usually occur in loose aggregates. They may either be needle-shaped or in the form of irregularly shaped flat disks. In most cases several crystals seem to be loosely stuck together. These aggregates have greater buoyancy than the small frazil crystals, and tend to collect together in open spaces of water. The effect of ripples would, perhaps, tend to make these aggregates collect. When the water is rippled by a light breeze the areas over which the crystalline aggregates have collected are marked out as calm spots or streaks. Surface tension is altered by the presence of the crystals, so as to prevent the formation of these 'capillary ripples.' Even during a brisk breeze these areas will be quite smooth, and thus the formation of thin surface ice is facilitated. These areas quietly merge into one another and the formation of surface ice begins rapidly, especially if the water is covered with floating cakes of ice with small interspaces of water.

Surface ice from frazil.

January 20, 1910.—Night clear, becoming overcast, with a little snow towards morning; overcast in the afternoon; calm.

Cap Rouge taken.

During the morning news was received that the ice bridge had formed at Cap Rouge about 8 p.m. the previous evening. At 11.30 a.m. the *Montcalm* left dock, followed by the *Lady Grey* at noon. On arriving at the Quebec bridge it was seen that two immense battures had met and locked together so as to block the gorge. From the piers of the bridge upwards for a distance of two miles the river was covered by successive sheets of heavy batture ice, showing several long pressure ridges, in many cases formed of piled-up blocks six or seven feet high. At this time the tide was still rising; at the edge of the ice the current was very strong, and the ice carried by the rising tide was often seen to be sucked underneath the surface ice. It was impossible to work under these conditions, for the strong current kept packing the ice in as fast as the ice breakers cut away large pieces. It was decided to wait until the turn of the tide, about 3 p.m. The steamers began to work at slack water, and as soon as a perceptible ebb had set in progress became rapid. The boats worked so as to cut a channel about 200 yards wide, and both made about the same rate of progress through the batture; the ice broke away

Cutting away the bridge.

between them in large pieces, which floated away with the tide. Several times the ice was so thick that the steamers lifted on to it, and were unable to back away (the *Montcalm* once and the *Lady Grey* three times). On these occasions it was only necessary for the disengaged ship to take a diagonal cut toward the ship that had become fixed; the ice cracked across and the imprisoned ice breaker was soon free. Working in this way, rapid progress was made toward the free water above. Greatest difficulty was experienced when only 250 feet of ice remained to be cut through. The ice was very heavy (15 to 20 feet), and here the steamers showed the greatest tendency to become stranded. Finally about 5.10 p.m. the bridge gave way, and the two boats retreated rapidly to Quebec, where they arrived about 6 p.m. At 10 p.m. news was received from Cap Rouge that the entire mass of ice had passed down.

A remarkable feature of the afternoon's work was the excellent work done by the *Lady Grey*. In spite of her lightness and comparatively small engine-power, she worked through the ice as rapidly, if not more so, than the *Montcalm*. Owing to her light weight, she was able to 'buck' into the ice and back away with greater rapidity, and on the whole was well able to keep up with the *Montcalm*. The latter was very slow in gathering speed and in starting ahead, owing to her low-pitch propellers.

Performance of the "Lady Grey."

January 22, 1910.—Rain during the night; rain at frequent intervals throughout the day. Large quantities of anchor ice coming down. Air temp.: max., 38° F., min., 33° F.

Anchor ice.

The *Lady Grey* left dock at 10.30 a.m. The ice was everywhere very open and loose. The rain and high tide had dislodged the battures to low-water mark. Large quantities of anchor ice were seen. Batture ice was met with in small pieces. The *Lady Grey* turned at St. Nicholas, and arrived in Quebec at 1.15 p.m.

January 23, 1910.—Rain during the night; overcast, with light snow in the morning; fine during the afternoon and early evening. Westerly wind. No frazil. Anchor ice coming down. Air temp.: max., 36° F., min., 26° F.

Anchor ice.

News was received on Saturday evening that the Ecureuil battures had given way, so that both the *Lady Grey* and the *Montcalm* were ordered out to prevent a possible jam at Cap Rouge. The *Lady Grey* left dock at 8 a.m., followed by the *Montcalm* at 9. The *Lady Grey* only met with two small battures below Quebec bridge, and above that point the ice was very loose and open and tended to crowd upon the north shore. The large battures expected had apparently passed down during the night. The *Lady Grey* turned opposite the Cap Rouge river, and arrived in Quebec about 10 a.m.

False alarm.

January 24, 1910.—Slightly overcast during the night; overcast during the day. E. breeze. Frazil—none.

No frazil.

The *Lady Grey* left dock at 8 a.m. The ice was very loose and open, and consisted largely of small blocks of thick batture ice (1 foot to 1½ feet thick). Opposite the Cap Rouge river a large batture (about ½ mile by ¾ mile) was met with. The rain and mild weather had greatly weakened it, and no difficulty was experienced in breaking it up. The light floating ice was remarkable for the quantity of mud it contained; since most of the battures have disappeared this ice had formed over the shoals and mud-flats at low water and was

Open water to Three Rivers.

Effect of no bridge in river above.

carried away by the next high tide. The river is reported open as far as Three Rivers. The fact that the Cap Rouge bridge is prevented from forming allows full play to the tides and currents, and so prevents the formation of any large quantity of heavy surface ice between Quebec and Three Rivers. The *Lady Grey* turned at St. Nicholas and arrived at Quebec at 10 a.m.

February 6, 1910.—Snow, with a strong W. wind, during the night. Fine and cold during the day. Wind W. and light. Air temp.: max., 5° F., min., —3° F.

The *Montcalm* left dock at 8 a.m. Below the Quebec bridge there was very little ice, although owing to the low temperature during the night the water was covered with a layer of very thin surface ice (⅛ to ¼ inch). This was, however, sufficient to prevent the formation of surface ripples by the wind. Above the Quebec bridge sheets of thin ice (2 to 3 inches) which had formed during the night were encountered. The *Montcalm* turned at St. Nicholas, and arrived in Quebec about 10.30 a.m.

Thin ice prevents ripples.

February 7, 1910.—Bar., 29.9. Clear and cold during the night. Fine and clear during the day. Wind W. and light. Frazil—large numbers of crystals (30 to 40 per c.c.) Air temp.: 0° F. and —7° F.

Frazil.

No true frazil noticed after this.

The *Lady Grey* left dock at 7.30 a.m. Before proceeding up the river, an hour was spent trimming down the batture opposite the guard pier. As a result of the extreme cold during the night there was a great deal of ice on the river, most of it between 4 and 6 inches thick. Above the Quebec bridge there was very little open water. Large fields which had been squeezed through the gorge and thickened up by piling were met with. The *Lady Grey* turned at St. Nicholas, and arrived in Quebec about 11.30 a.m.

February 8, 1910.—Clear and cold during the night, becoming overcast about midnight. Light snow towards morning and during the day. Wind E. and light. Air temp.: max., 16°, min., —4°.

During the afternoon of February 7 a series of measurements were made on the rate of growth of surface ice. A little of the ice which formed in an open space near the ship in dock (the *Lady Grey*) was broken away from time to time and the pieces taken on board and measured. The results are tabulated below. It was impossible to continue the measurements during the night. The next morning snow had set in and the tides had broken up the surface sheet. The observations are given below:—

Observation on rate of growth of surface ice.

Time	Thickness of Ice in Cms.	Air Temperature.	Water Temperature.
		Fahr.	
11.30 a.m.	No ice.	4°	+ ·092° C.
12 noon	Thin scum.	3	
12.20 p.m.	0·31 cm.	2	+ ·068°
1.05 "	0·62 "	1	+ ·053
1.35 "	0·9 "	0·5	+ ·053°
2.05 "	1·1 "	−1	
2.35 "	1·3 "	1°	
3.05 "	1·6 "	−1	+ ·045
3.35 "	1·8 "	1·05	
4.05 "	1·9 "	2	
5.05 "	2·3 "	−3·5	

February 10, 1910.—The *Lady Grey* left dock at 11 a.m. An especially high tide during the night caused by the easterly gale had dislodged the battures above Cap Rouge. On the way up the river several large and heavy pieces were encountered, some of them running up to two feet of uniform ice. There was very little open water, and the ice became more and more crowded in the neighbourhood of the gorge. It was found impossible to make headway beyond the piers of the Quebec bridge. Large sheets of heavy batture ice could be seen crowding through the narrow gorge and giving rise to heavy ice-shoves on shore. As soon as the ice-sheets had forced their way beyond the piers of the bridge the release of pressure caused them to crack in all directions and to break up into small pieces. The current was moving faster than the ice, and on one occasion the pressure was so great that the moving masses of ice nearly came to a standstill. These heavy battures had been in formation during the entire winter, and were thought to come from Les Ecureuils. The January thaw had not been sufficient to release them. The *Lady Grey* remained at the Quebec bridge, breaking up the large blocks as they shoved through the gorge, to diminish the chances of a jam with the rising tide. The *Lady Grey* arrived in dock about 2.30 p.m.

Jam of ice in the gorge.

February 23, 1910.—Bar., 29.70. Fine and clear during the night, and fine and clear during the day. Air temp.: max., 18°, min., 5°.

The *Lady Grey* left dock at 9.30 a.m. Up to the Quebec bridge and beyond as far as St. Nicholas a heavy batture of autumn-old ice was met with, about two miles long and a mile or so wide. An actual measurement gave 25 inches thickness of solid ice; in many places it was much heavier than this, and large quantities of frazil were confined beneath the ice. This batture was much the heaviest encountered this year. The *Lady Grey* kept at work on this field of ice, cutting it up into several pieces, until the ebb tide had almost carried the ice through the Cap Rouge gorge. At 12.30 it was thought prudent to retire to the Quebec side of the bridge and wait to see these pieces through. As it was, several of the pieces were large enough to reach from shore to shore, and were considerably retarded and at times almost stopped in squeezing through. However, by working from the down-stream side these pieces were broken up and helped through, so that by 1.30 p.m. the batture had passed down. The *Lady Grey* then proceeded up the river as far as the Cap Rouge river to make sure that there were no more battures. Only large sheets of thin ice from 2 to 3 inches thick were met with. These sheets were so wedged in with the two banks that the ice was subjected to a considerable compressional strain. It was interesting to notice the difficulty experienced by the *Lady Grey* in moving through this ice when the sheet was unable to give way on either side. As much difficulty was experienced in making way through this thin ice as in cutting through a freely floating cake of ice a foot thick. In many cases the sheet could be seen to buckle and give way with a loud report, while a crack spread from the fault towards the shore. As soon as this had taken place the ice breaker immediately gained speed. The *Lady Grey* arrived in dock about 2.45 p.m.

Attack on a batture

Difficulty of cutting fixed ice.

A series of measurements of water temperatures in the Louise basin were taken at different depths to 34 feet. The result shows a rise of temperature with depth. However, the temperature of the

Effect of ship's heat on water temperature.

water proved to be very unsteady throughout any length of time. The results are given below and shown in diagram 1:—

Depth.	Time.	Sc. Reading.	Cms. Bridge Win.	Temp. in Degree C.
1 foot.	2.50 p.m.	38·45	2·95	+ ·048
5 feet.	3.00 "	·65	2·75	·045
12 "	3 09 "	·13	3·25	·053
20 "	3.25 "	36·85	4·55	·074
31 "	3.30 "	35·55	5·85	·096
20 "	3.37 "	37·35	4·05	·061
5 "	3.46 "	36·20	5·20	·085
1 foot.	3.55 "	34·50	6·90	·113

No frazil.

March 2, 1910.—Overcast, with snow and E. wind during the night. Overcast and foggy during the morning; calm. Fog lifts about 2 p.m. No frazil. Large quantities of snow scum. Water temp.: Sc. R. 39·7, T. + ·0305° c. Air temp.: max., 34°, min., 27°.

The *Lady Grey* left dock at 1.20 p.m. As far as the Quebec bridge the river was remarkably free from ice. Above this point numerous small cakes of heavy batture ice were met with. Some of these were as much as 3 to 4 feet thick. No very large pieces were seen. The *Lady Grey* turned at St. Nicholas, and arrived in Quebec at 4 p.m.

Water temperature lower at night.

WATER TEMPERATURES (IN DOCK).

—	4.25 p.m.	5.10 p.m.	6.30 p.m.	7.30 p.m.	11.15 p.m.	9 a.m., (Mar. 3.)
Sc. R.	36·4	33·5	38·7	39·2	39·5	36·0
T.	+ ·084° C.	+ ·131° C.	+ ·047° C.	+ ·039° C.	+ ·034° C.	+ ·091° C.

March 3, 1910.—Bar., 29.70. Fine and clear during the night; same conditions throughout the day. Wind W. and moderate. Air temp.: max., 38°, min., 25°.

River almost free of ice.

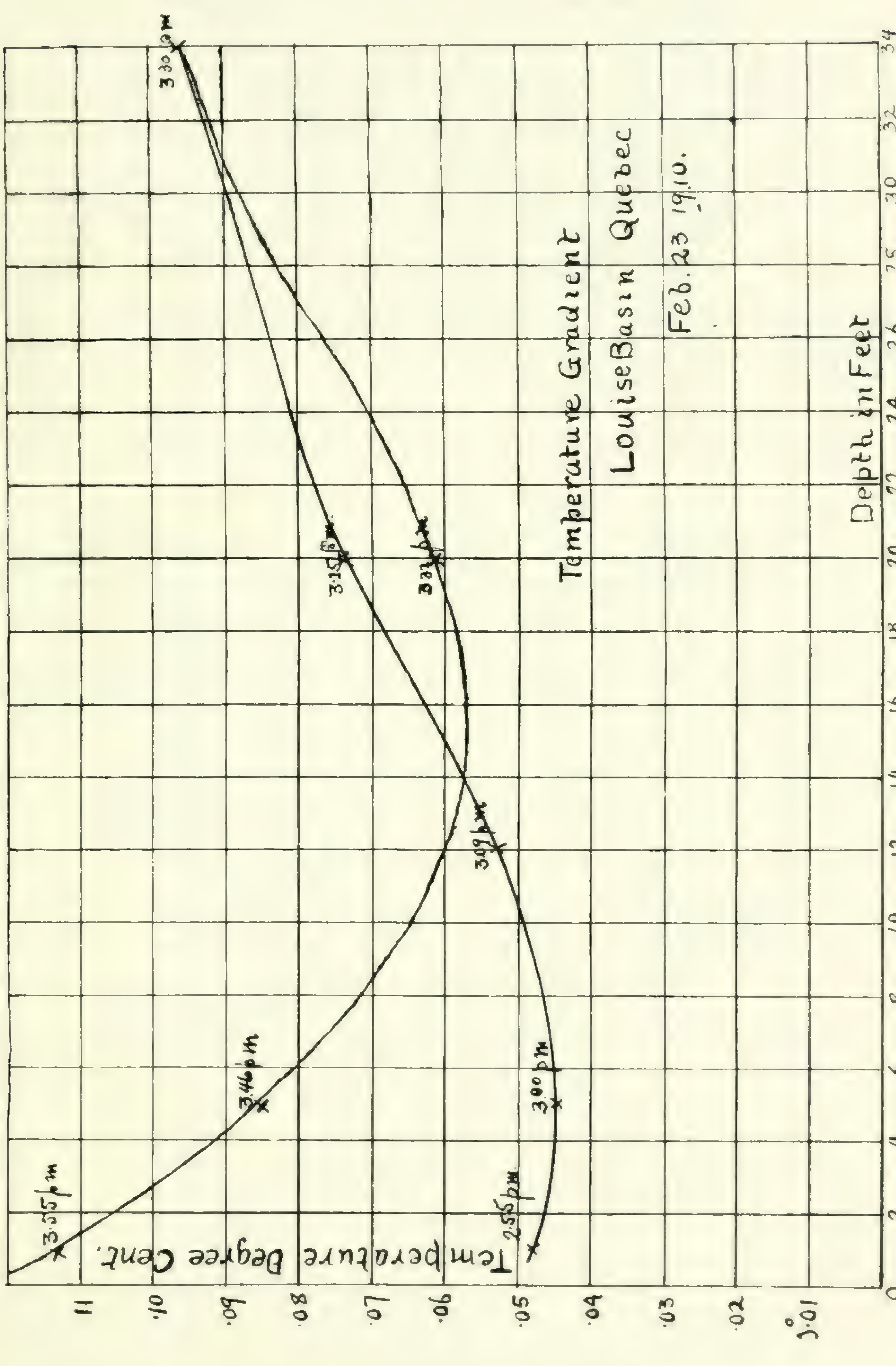
The *Lady Grey* left dock at 1.30 p.m. The river was almost entirely free from ice below the Quebec bridge. At this point a floe consisting of small pieces of heavy batture was met with; some of the pieces were between 3 and 4 feet thick. None of the pieces were at all large. At St. Nicholas and above the river was seen to be almost entirely free from ice. The *Lady Grey* turned at St. Nicholas semaphore, and arrived in Quebec about 4.15 p.m.

River temperature.

WATER TEMPERATURES.

9 a.m. (in dock).	3 p.m. (in channel).	4 p.m. (in dock).
+ ·091° C.	+ ·099° C.	+ ·118° C.

Figure No. 1.



Effect of ship in warming the water.

March 4, 1910.—Bar., 29.95. Fine and clear during the night; same throughout the day. Wind W. and moderate. Air temp.: max., 32°, min., 18°.

The *Lady Grey* left dock at 1.20 p.m. The river was practically free from ice as far as the Quebec bridge. Opposite the Cap Rouge river a large batture was met with; it was about a mile long and one-quarter mile wide. The ice was not very heavy, and was for the most part from 12 to 15 inches thick. The batture was thought to have come from Cap Santé. This field of ice was cut up into several pieces. On the way to St. Nicholas a few small battures were met with, but for the most part the river was almost clear of ice or covered with a very thin sheet. The *Lady Grey* turned at St. Nicholas semaphore, and arrived in Quebec about 4.30 p.m.

Water temperature rising

WATER TEMPERATURES.

—	3 p.m. (in channel).	4.30 p.m. (in dock).
T. .	- 107° C.	+ ·110° C.

March 5, 1910.—Fine and clear during the night; overcast, with light snow, during the morning. Snow ceases towards noon, but the sky remains overcast. Large quantities of floating snow-scum. Air temp.: max., 30°, min., 19°.

The *Lady Grey* left dock at about 1.30 p.m. The river was almost entirely free from ice both above the Quebec bridge and below. A few moments were spent in slicing off the Cap Rouge batture. The *Lady Grey* arrived in dock about 4 p.m.

River temperature rising.

WATER TEMPERATURES.

—	9 a.m. (in dock).	3 p.m. (in channel).	4.15 p.m. (in dock).
T.	+ ·091° C.	+ ·123° C.	+ ·107° C.

March 6, 1910.—Bar., 29.95. Fine and clear during the night—heavy fog prevailing—calm at noon. Fine and clear during the afternoon, with light E. breeze. Air temp.: max., 34°, min., 14°.

No ice formed, due to warm water.

The *Lady Grey* left dock at 1.30 p.m. There was practically no ice on the river—a few small cakes of heavy batture ice at intervals and a few large sheets of very thin surface ice. The *Lady Grey* turned opposite St. Nicholas semaphore, and arrived at Quebec about 4 p.m.

Rising river temperature, due to no floating ice and open water.

WATER TEMPERATURES.

At 3 p.m. in channel.	3 feet under ice	+ ·140° C.
	3 feet in open water	+ ·148° C.
	at surface (sun obscured)	+ ·143° C.
	3 feet deep (" ")	+ ·135° C.
At 4.15 p.m. in dock	surrounded by ice at surface	+ ·055° C.
	depth of 3 feet	+ ·099° C.
	" " "	+ ·123° C.

March 15, 1910.—Fine and clear during the day. Air temp.: max., 26°, min., 16°.

The *Montcalm* left dock about 1 p.m. On arriving at the Quebec bridge it was found that a jam had taken place between the piers of the bridge. At 3 p.m. the *Lady Grey* received a Marconigram to the effect that her assistance was required. By the time the *Lady Grey* had arrived on the scene it was discovered that another batture had jammed opposite Confederation point. The two boats worked as already described, cutting a channel about 500 feet wide, and bucking into the ice, which floated away with the ebb tide. The *Lady Grey* again showed that she was able to do as much work as the *Montcalm*. The latter steamer was only generating about 3,000 h.p. instead of her maximum 4,200 h.p.

Ice bridge taken.

The two boats worked in the manner described until 6 p.m., when the ice-bridge finally gave way. The boats arrived in Quebec about 7 p.m.

March 16, 1910.—Wind E. and light. Clear and fine during the night; light snow towards morning.

8.05.—The *Lady Grey* left Quebec. River up to the Quebec bridge practically free from ice.

8.45.—On arriving at the Quebec bridge an enormous batture, about 1½ miles long and from 3 feet to 15 feet in thickness, was found blocked in the gorge. The tide was rising, and on approaching to within a ship's length it was observed that the mass of ice was giving way before the flood tide. The steamer waited about ten minutes for the batture to ascend some distance, and then cut its way around the edge. A communication was sent to the *Montcalm* to come up and break up this batture before it descended with the ebb tide. The *Lady Grey* then proceeded on her way up to Three Rivers.

'Lady Grey" met batture in gorge.

'Lady Grey" on way to Three Rivers.

March 17, 1910.—Clear and fine during the night. Same during the day, and very cold, with westerly breeze. Frazil in water—none. Air temp.: max., 22°, min., 0°.

Note on the Formation of Ice Over Lake St. Peter.

The thin ice which forms in the fall over Lake St. Peter becomes jammed in the narrow channel opposite Port St. Francis, at the outlet of the lake, where the river is crossed by shoals. In this way the river between Port St. Francis and Three Rivers is frozen over solid before the lake itself. In the spring the reverse happens. The river above Lake St. Peter is often clear of ice before the lake, which generally begins to give way at the head before the ice moves at the outlet. The broken ice from the river above the lake is carried under the still solid lake ice, and is apparently melted away at the head of the lake by the comparatively warm water (perhaps 1° C.), which has become somewhat heated by the sun's action on the open water in the upper reaches of the river. By the time the water reaches the foot of the lake it is cooled down so near to zero that it has little or no effect in melting and weakening the ice at the foot of the lake.

Formation of ice on Lake St. Peter.

Lake ice gives first at head of lake.

The *Lady Grey* left dock at 6.30 a.m., and attacked the ice about one mile above Three Rivers at 7. The ice was found to be very much harder and tougher than on the preceding day. The weather had turned cold (near zero) during the night, and a wind had made the air very dry (relative humidity between 50 per cent and 70 per

Effect of cold water and humidity on the ice.

cent). Headway through the ice was made very slowly, but slightly better progress was made during the afternoon. In thickness the ice varied between 15 and 20 inches of clear blue ice, with about 6 inches of snow on the surface. Advance could be made only by repeated 'buckings.' The *Lady Grey* would back down about 200 feet and advance between 60 and 100 feet into the ice. By working in this way a channel was cut about 200 to 300 feet wide and three miles long during the day's work of ten hours. The difficulty in cutting through the ice was due to the fact that there was no give to the ice on either side. On the return journey to Three Rivers at 5.15 p.m., the *Lady Grey* was able to widen the channel by slicing off a strip 200 feet on the north side of the channel. She was able to cut through this ice without stopping at a speed of about six miles per hour, with the current of about three miles per hour. This gives one an idea of the necessity of specifying the boundary conditions (whether free or fixed) of a sheet of ice in speaking of the rate of progress through it. By having two boats to 'buck' alternately into the ice in parallel directions the ice is enabled to give more readily, and progress can be made about three times more rapidly.

No "give" to the ice.

Need to specify conditions for breaking ice.

Block of Lake Ice turned up on end.

Structure of surface ice.

The ice which was cut through presented several very remarkable features. Most of it was the clear, blue, snow-covered ice already mentioned, and some of it showed distinct striations. In several spots there appeared considerable quantities of frazil ice when ice-blocks split away. In a large number of cases the entire thickness was seen to be made up of a succession of plates of thin ice (about one inch) cemented together, many of them carrying mud and silt. In many cases the muddy ice was directly on the underside of the conglomerate mass. The occurrence of ice of this kind confirms the statement already made that the thin surface ice of the lake is carried under the ice already formed at Port St. Francis in the fall. The

interesting point to note is that this muddy ice must have been deposited before the lake became frozen over solid, so that the conglomerate ice had apparently not thickened after that time (two months at least). This gives some support to the view that a limiting thickness is formed fairly early in the winter, and that the ice does not thicken much beyond that amount. Limiting thickness of ice.

A water temperature was taken at the edge of the ice at 6.55 a.m. Both the readings indicate a lower temperature than was ever recorded at Quebec even during the severest weather. This gives an indication of the power of the sun in keeping the water slightly above zero when the surface is free of ice, as it was during the winter between Three Rivers and Quebec. The current in the channel cut out by the *Lady Grey* was about three miles per hour. On returning to dock about 5.50 p.m., thin surface ice was already forming over the water opposite Three Rivers in spite of a light breeze. This gives an idea of the rapidity with which surface ice forms when the air is dry (about 60 per cent relative humidity), and the water near zero even if the air temperature is moderately cold (about 15° F.). Effect of surface ice on temperature of water. Effect of humidity on formation of ice.

March 18, 1910.—Fine and clear during the night; fine and clear during the entire day. Heavy hoar-frost mist on the river during the early morning.

The *Lady Grey* left dock at 9 a.m. On the way to the end of yesterday's cut the existing channel was widened by 100 to 200 feet. Work was begun at the end of the cut at 9.35. The ice was not so hard nor so tough as on the preceding day—the humidity had risen to 90 per cent during the night. Progress on the whole was slower than on the preceding day. A channel about 300 feet wide was cut as far as the wharf at Port St. Francis by 5.10 p.m., giving a progress of two miles in 7¾ hours. The ice was almost altogether of the conglomerate variety already described, and in many cases there were frazil accumulations to a depth of 4 to 6 feet under the ice. These spots retarded very considerably the progress of the work. On returning to Three Rivers the channel was widened out by about 200 feet. The *Lady Grey* went into dock at 6.15 p.m. Effect of humidity on ice breaking.

March 19, 1910.—Fine and clear during the night; fine and clear during the morning. Sky becomes overcast towards noon; sleet and rain about 3 p.m. Overcast with occasional showers. Air temp.: max., 35°, min., 6° F.

The *Lady Grey* left dock at 6.30 a.m. A water temperature was taken just opposite Three Rivers (T. + ·09° C.). On the way to the head of the cutting a little above the wharf at Port St. Francis the steamer was run at full speed along the channel. The ship-waves thus created did considerable service in widening the cut. The waves had little effect so long as the wave-fronts were at right angles to the edges of the channel. Whenever the waves cut the edge of the ice at a small angle they had considerable effect in breaking up the ice. Effect of ship waves in ice breaking.

Work was begun at the head of the cutting about 7.15 a.m. At first the ice proved to be fairly heavy and the rate of progress was about the same as on the preceding day. Some distance ahead could be described a line of 'air-holes' in the ice in the position indicated in the map. The ice proved to be considerably thinner as these holes were approached (about 15 inches). Here the most efficacious method of making progress was to back three or four hundred yards to enable Appearance of air holes in the ice.

Method of employing ship waves.

the ship-waves to come into play and travel into the ice. It was then only necessary to keep to our side of the channel; the ship's waves followed the ice breaker and broke up the ice two or three hundred feet to one side. Whenever the ice exceeded 15 inches or so in thickness this method was not so advantageous, the effect of the waves being then very much less. The *Lady Grey* made her way into one of the air-holes mentioned at 10.05 a.m. Although the ice was thinner here than elsewhere (about 15 inches), it ended abruptly at the edge of the hole with a thickness of about 12 inches. A water temperature taken here gave a very steady reading at 34·3, which corresponds to a temperature, T. = + ·118° C. This open space was one of a chain extending across the outlet of the lake and just over a shoal almost (excepting in the ship channel) crossing the entire river. This would seem to indicate that the warmer water of the bottom of the lake is here thrown upwards to the surface. The fact that these air-holes have remained open all winter is a striking point in support of the conclusion made in connection with the 'Rate of Growth of Surface-ice,' in which results are given to show that when the temperature of running water is slightly above zero ice will not form unless the mean air-temperature is below a certain limit (the approximate figures are for water temperature, + ·118° C.; ice will not form unless the mean temperature is below 8° F.).

Temperature of water in air hole.

Probable cause of air holes in the lake ice.

By 4.50 p.m. a channel was cut along the ship channel about 1,000 feet beyond the sunken wharf, giving a total of 4½ miles, or an average rate of about one-half mile per hour. The lake ice is mostly about 15 inches of clear, blue ice, with about six inches of frozen snow on top. In certain places there were frazil accumulations; in others the ice showed a rotted appearance (a columnar structure at right angles to the surface). The clear, hard ice was always deeply pitted on the under surface. A water temperature was taken at the end of the cut just before turning back (at 4.50 p.m.), Sc. Reading 37·5 (somewhat unsteady), giving T.= + ·066° C. This temperature although taken later in the day was much colder than that of the air-hole. The *Lady Grey* returned along the channel already cut out, and went into dock at 5.40 p.m.

Appearance of broken ice.

Water temperature at end of day's cut.

March 20, 1910.—Clear during the night; fog and rain towards morning; fog and mist until 1 p.m., when weather clears; fine during the afternoon and evening. Air temp.: max., 36° F., min., 28° F.

The *Lady Grey* left dock at 8 a.m. On the way some time was spent widening the cut near Nicolet Traverse. Work was begun at 9.30 a.m. at the head of the cut, 1,500 feet above No. 8 Lightship. Progress was made at the rate of one-half mile per hour. The rain had softened the ice, which was honeycombed in several places. The effect of the rain was seen in the high water-temperatures observed during the day.

Effect of rain on the ice and temperature of river.

9.30 a.m., near No. 8 Lightship. Sc. R., 34·5, T.= +·115° C.

4.50 a.m., at end of cut 7,500 feet above No. 35 Sc. R., 31·5, T.= + ·165.

By 4.50 p.m. the cut had advanced 7,500 feet above No. 35 light, giving a total of 18,600 feet during the day, or a little more than 3½ miles. The *Lady Grey* docked at Three Rivers about 5.50 p.m.

March 21, 1910.—Bar., 30.05. Fine and clear during the night; fine and clear during the day. Air temp.: max., 36°, min., 16°.

The *Lady Grey* left dock at 6.30 a.m., and proceeded to the end of the last day's cut. On the way a water temperature was taken with the ship moving at full speed. The reading was fairly steady, and gave, Sc. R., 35·5; T.=+·099. The *Lady Grey* continued to cut along the channel, and made an average rate of progress of one-half mile per hour. By 4.50 p.m. the total made was a little less than five miles. The ice showed a much more rotten appearance than on the preceding day.

A water temperature taken at the end of the cut before turning gave, Sc. R., 38·5 (somewhat unsteady); T.=+·050. On the return journey readings were taken at full speed.

Temperatures show rise of water temperature down the new cut.

Along the channel between No. 47 and 35........	Sc. R.	37·0	T = + ·075
Between No. 13 and No. 6......................	Sc. R.	33·9	T = ·125
A further series of readings gave.		35·0	·107
		35·4	+ ·100
		34·9	+ ·109
		36·0	+ ·091

The *Lady Grey* put into dock at Three Rivers about 6 p.m.

March 22, 1910.—Water rises 5 inches; height, 33 feet 3 inches. Overcast during the night, with rain and hail during the morning. Clears up and is fine and calm from 2 p.m. Air temp.: max., 40°, min., 28° F.

The *Lady Grey* left dock at 8.10 a.m. On arriving at Port St. Francis it was seen that the ice to the north of the channel between Three Rivers and Port St. Francis was moving down. The ice had given way along a fissure from No. 8 Lightship along the Pointe du Lac lights, and the portion to the south of this bounded by the cutting along the Nicolet Traverse began to move down. The *Montcalm* remained at work below Port St. Francis, cutting up the large fields as they came down, while the *Lady Grey* worked wherever the water was deep enough between No. 8 Lightship and Port St. Francis. The water was so low that the ice grounded on the shallow shoal in the neighbourhood of the Batture au Fer. By the time the boats left for Three Rivers a great deal of ice had passed down—but a large piece was coming down slowly over the shoal opposite Port St. Francis.

Ice begins to move out.

By 8 p.m., a great deal of this ice had given way and was seen descending opposite Three Rivers.

WATER TEMPERATURES.

8.45 a.m.	Half mile below Port St. Francis..........	Sc. R.	35·0	T = + ·107
2.00 p.m.	Near fissure near No. 8 lightship.........		29·0	T = + ·206
4.00 p.m.	Opposite Point du Lac shoal in channel...		36·0	T = + ·091
5.34 p.m.	Between Port St. Francis and Three Rivers		37·7	T = + ·068

March 23, 1910.—Bar., 30.12. Water height, 33 feet 11 inches. Fine and clear during the night; fine and clear during the afternoon; sky becomes overcast towards 6 p.m. Air temp.: max., 46°, min., 19°.

After taking on coal, the *Lady Grey* proceeded up the river. The ice cut away on the preceding day had become stuck on the shoal opposite Port St. Francis. This ice was cut through and dislodged. The *Lady Grey* spent the day cutting away the ice at the foot of the lake wherever the depth would allow, while the *Montcalm* worked opposite Port St. Francis to keep the ice moving. The area cut away at the end of the day is shown on the rough sketch map, fig. 2. The *Lady Grey* returned to dock at 5.45 p.m.

WATER TEMPERATURES.

9·20 a.m. Near No. 25.... .. .. Sc.R. 38·9 T = + ·043°. Boat stationary.
11·20 a.m. Between No. 8 light and No. 47. Boat going at full speed up the river.
Sc. readings taken every half minute:—
35·0 + ·107 34·5 + ·115 34·0 + ·124 33·5 + .131 33·0 + ·140
32·5 + ·148 32·0 + ·157 32·5 + ·148 33·0 + ·140 33·0 + ·140
33·5 + ·131 33·0 + ·140 33·0 + ·140.

March 24, 1910.—Water rose 9 inches. Overcast during the night; fine and clear during the day. Air temp.: max., 44°, min., 27°.

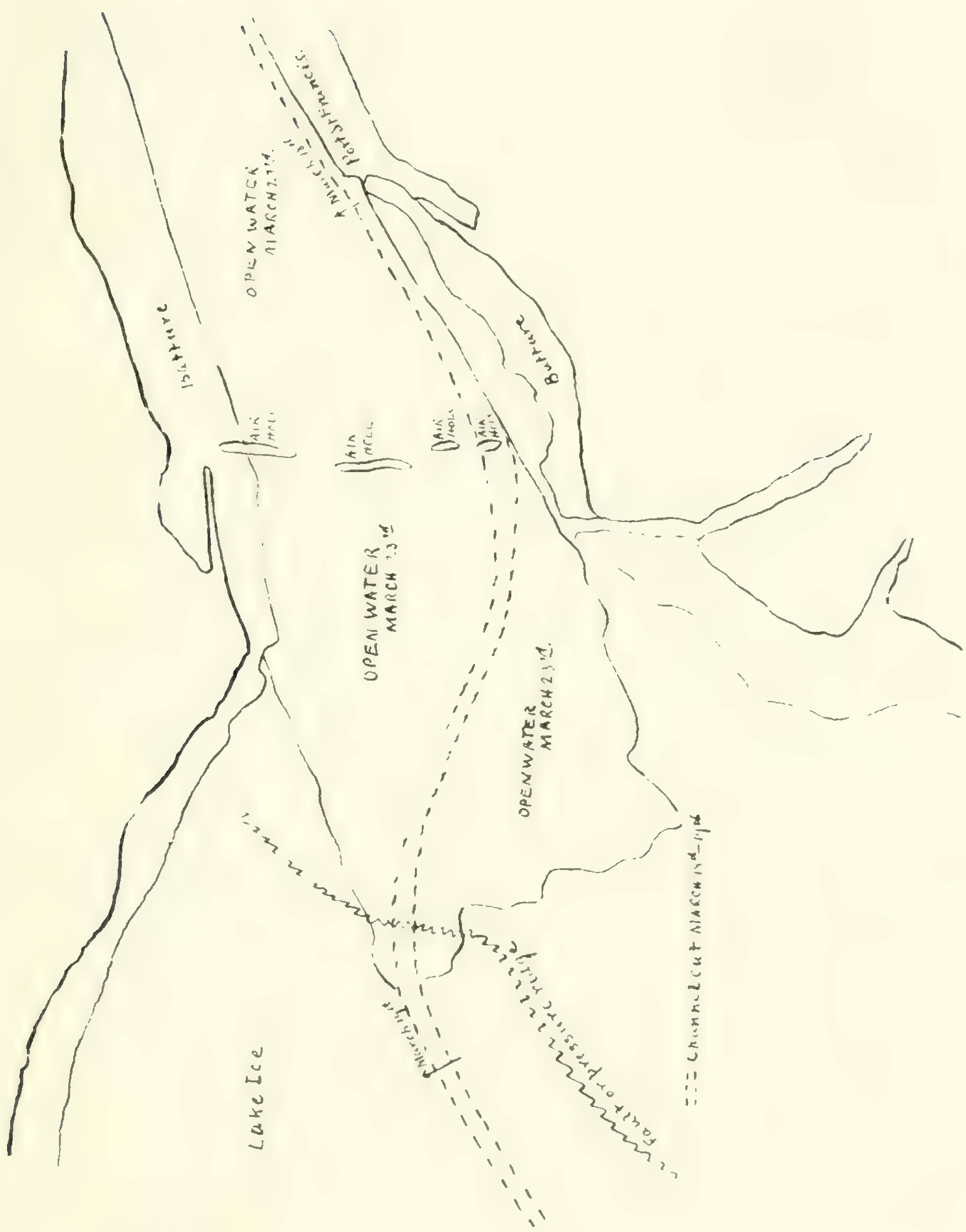
The *Lady Grey* left dock at 6 a.m., and proceeded up the river to break away ice in the neighbourhood of Banc des Anglais wherever the depth of water would allow. The *Montcalm* steamed at full speed along the channel of Point du Lac lights; the ship-wave generated had a very considerable effect in breaking away the ice and so widening the channel. About 11 a.m. the *Lady Grey* did the same, and again about 2.30, the interval being employed in cutting into the ice, sounding continually for depth. The ice became very soft about 1 p.m., and water could be made out flowing over the ice on the south shore. The *Lady Grey* stopped work at 3 p.m., and waiting until 5.40, since the ice had been cut away wherever it was safe to go. The effect of the ship's swell made in going up and down the channel was instrumental in dislodging and sending down several large pieces which came down in the course of the afternoon. The *Lady Grey* left for Three Rivers at 5.20 p.m., and put into dock about 6.20, after

Effect of ship waves.

Ship waves from 'Lady Grey.'

spending some time in dislodging a field of ice which had stopped on the shoal opposite Three Rivers.

FIGURE No. 2.



Progress of Ice Breaking, Lake St. Peter, March 18-19, 1910. Scale, 3,000 feet=1 inch.

FIG. 2.—Showing how the narrow cut started the lower lake ice.

Temperature of open river follows the air temperature.

Water temperatures taken throughout the day followed roughly the air temperatures:—

6.40 a.m.	Near No. 13	Sc. R. 40·8 T	+ ·013°
10.45 a.m	In channel near No. 35—		
	Sc. R. 36·0	35·5	36·0	36·0	35·5
	T. + ·091	+ .099	+ .091	+ ·091	+ ·099°
10.45 a.m.	In channel near No. 57.................	Sc. R. 35·5 T =	+ ·099°
1.45 p.m.	Near No. 8 lightship.....................	32·0	+ ·157°
2·10 p.m	" "	31·0	+ ·173°
4.00 p.m.	Quarter mile from light 35	39·0	+ ·042°
4.40 p.m.	" " "	39·8	+ ·029°

March 25, 1910.—Height of water, 35 feet morning, 35 feet 6 inches evening. Overcast during the night; overcast during the day; white fog about 8.30 a.m. Overcast during the remainder of the day. Air temp.: max., 35°, min., 30° F.

The *Lady Grey* left dock at 6.10 a.m., and proceeded to steam at full speed along the channel in Lake St. Peter. At 8.30 a.m. fog obliged the ice breaker to stop work. The *Lady Grey* stopped near the Nicolet light until 3.30 p.m., when another run was taken along the channel. The *Lady Grey* went into dock about 5.40 p.m.

WATER TEMPERATURES.

7.00 a.m.	Sc.R. 41·0	T =	+ ·010.	Nicolet Traverse.
3.00 p.m.	37·0		+ ·075.	In channel along Point du Lac lights.

March 26, 1910.—Height of water, 36 feet. Overcast during the night; overcast during the afternoon; clears up about 6.30 p.m., and again becomes overcast about 9 p.m. Air temp.: max., 44°., min., 28° F.

After taking on coal, the *Lady Grey* left dock at 9.30, and steamed at full speed along the channel to one mile below No. 57 buoy. Anchored about 11.30 a.m., and remained at anchor until 3.15 p.m., when another run was made along the channel. The *Lady Grey* arrived in dock about 5.10 p.m.

Effect of sun on temperature of water.

WATER TEMPERATURES.

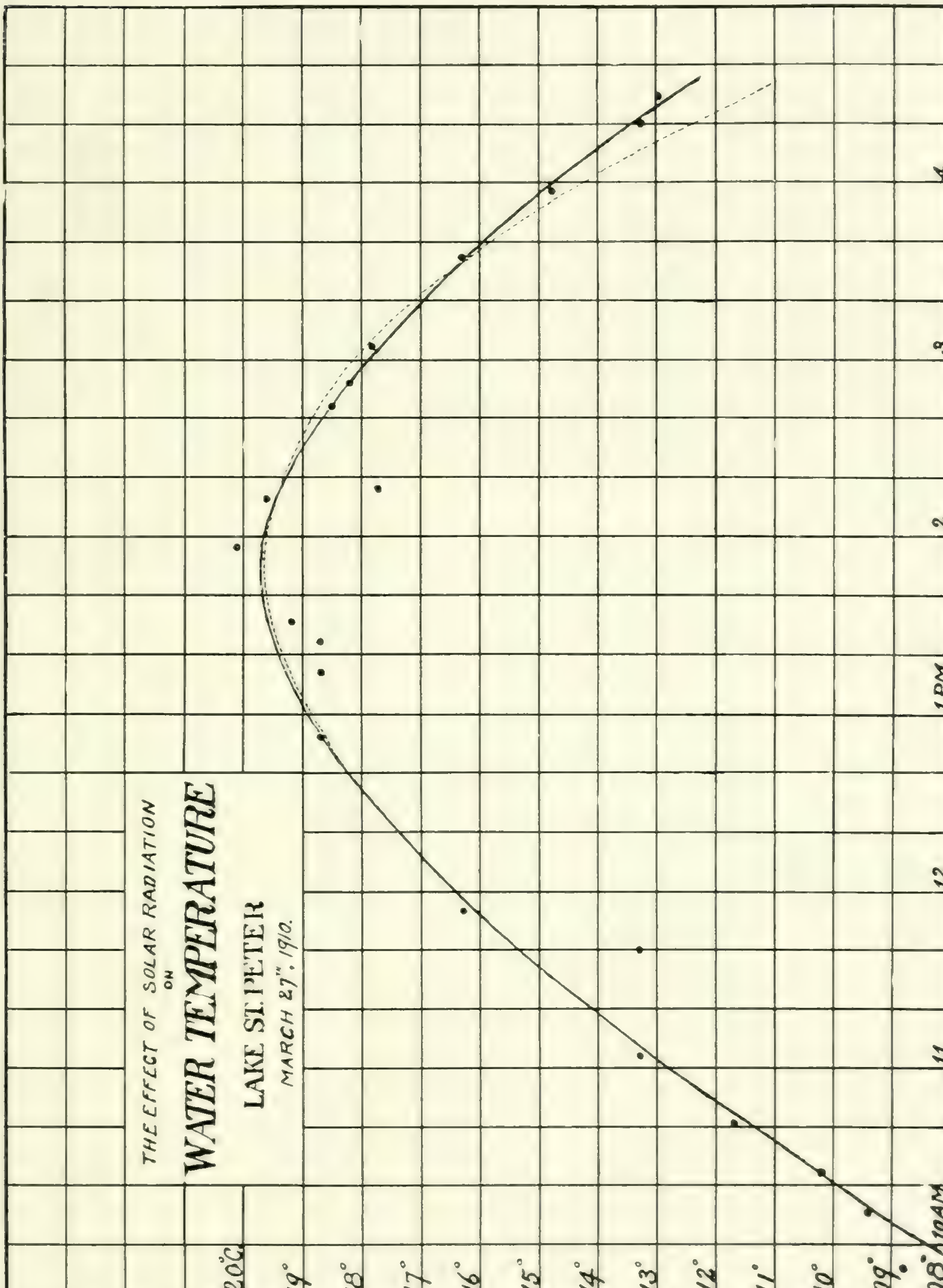
9.30 a.m.	Sc.R.	39·5	T = + ·034° C	Between Three Rivers and Port St Francis channel ½ mile below No. 57
11.00 a.m.		38·5	+ ·050	
12.30		38·9	·043	At anchor above Nicolet Lt. Sky overcast—current 1½ m. per hour. Ice about 1½ miles upstream
12.45		39·1	·046	
1.05		39·1	·040	
2.00		39·1	·040	
2.33		37·2	·071	Sun shining. Thermometer in shade.
2·39		36·6	·081	
2.46		36·6	·081	
2.50		36·8	·078	Sun clouded.
2.56		37·0	·074	
3.00		36·5	·082	Sun shining.
3.15		36·5	·082	

These measurements show very markedly the effect of the sun in raising the water temperature.

March 27, 1910.—Height of water, 36 feet 4 inches morning, 36 feet 8 inches evening. Fine and clear during the night; fine and clear during the day. Air temp.: max., 42°, min., 23° F.

The *Lady Grey* left dock about 8.30 a.m., and proceeded up the river. The entire day was passed at anchor about one-half mile above the Nicolet light. An interesting series of measurements, showing the heating effect of the sun on the water, was taken. The current

FIGURE No. 3.



Absorption of Sun's heat by water.

Effect of sun in warming water.

was about 1½ miles per hour, and the edge of the ice-field about 1½ miles up-stream:—

Time of Day.	Time.	Sc. Reading.	Temp.C.	Air Temp.	Real Humidity
9.52 a.m.	0	36·5	+ ·088°C		
10.11	19	35·8	094	41 F	51%
10 25	33	35·3	·102		
10 41	49	34·4	·117		
11.04	72	33·4	·133	33°	43%
11.40	108	33·4	·133		
11.53	121	31·0	·163	36°	48%
12.52 p.m.	200	30·2	·187		
1.24	212	30·2	·187		
1.31	219	29·9	·192		
1.56	244	29·3	·201		
2.13	261	29·6	·196	40°	52%
2.44	292	30·3	·185		
2.52	300	30·5	·182		
3.05	313	30·7	·178	41	50%
3.35	343	31·6	·163		
3.58	366	32·5	·148	42°	53%
4.20	388	33·4	·133		
4.30	398	33·6	·130	42	69

These results are given on the accompanying curve. As we should expect, the curve of temperature is a portion of a sin-curve, since the amount of heat received from the sun per unit area is proportional to cos α, when α is the altitude of the sun at any time, and α is, of course, proportional to the time.

March 28, 1910.—Bar., 29.65. Height of water, 36 feet 9 inches morning, 37 feet evening. Fine and clear during the night; overcast towards morning; squall of wind and hail about 8.30 a.m.; clears up about 11 a.m., and is fine and clear during the remainder of the day. Air temp.: max., 44°, min., 28° F.

Waiting for lake ice to move down.

The *Lady Grey* left dock at 6.30 a.m., and proceeded up to the head of the cut in Lake St. Peter. Ice there still fairly firm. The channel was enlarged wherever the depth of water would allow. The *Lady Grey* came to anchor at the foot of the lake until 2 p.m. The remainder of the afternoon was spent cutting into the ice wherever the water was deep enough. Owing to the height of the water it was possible to cut away several large pieces. The *Lady Grey* returned to dock about 6 p.m.

Overcast sky produces low water temperature.

WATER TEMPERATURES.

8.00 a.m.	Sc.R. 40·9	T. = + ·011°
10.00 a.m.	39.3	+ ·037 at head of cut.

The effect of the overcast sky was to give very low temperatures.

March 29, 1910.—Height of water, 37 feet 1 inch morning, 37 feet 1 inch evening. Fine and clear during the night; fine and clear during the day. Air temp.: max., 50°, min., 36° F.

The *Lady Grey*, after taking on coal, left dock at 9.30 a.m. A trip was made along the channel, after which the *Lady Grey* anchored about one-half mile above Nicolet light. Temperatures were taken

at short intervals until 2.16 p.m. A curve similar to that obtained on March 27 was obtained:— Absorption of sun's heat in the water.

Time of day.	Time.	Sc. R.	Temp.
9.30 a.m.	0	35·3	+ ·102°C.
11.25	115 min.	32·3	+ ·152
11.36	126	32·0	+ ·157
11.47	137	31·2	·170
12.09	159	30·6	·180
12.23	173	29·7	·195
1.11 p.m.	221	28·4	·216
1.35	245	27·8	·226
1.58	268	29·7	·195
2.16	286	28·8	·211

Towards 2 p.m. the *Lady Grey* proceeded dead slow against the current up to the edge of the ice, a distance of 12,200 feet. Temperatures were taken at intervals of a minute to the edge of the ice. In this way it was possible to show the temperature gradient towards the edge of the ice:— Showing effect of ic on temperature of water.

Time of day.	Time.	Sc. R.	Temp.
2·16	80	28·8	+ ·210°C.
2·18	78	·9	·208
2·19	77	29·0	·206
2·20	76	·1	·205
2·22	74	28·7	·211
2·23	73	29·1	·205
2·24	72	·2	·203
2·25	71	·1	·205
2·27	69	·5	·198
2·29	67	30·1	·188
2·30	66	·2	·186
2·31	65	·3	·185
2·32	64	·3	·185
2·33	63	·6	·180
2·34	62	·2	·186
2·35	61	·5	·182
2·36	60	·8	·177
2·37	59	31·0	·173
2·38	58	30·8	·177
2·39	57	·5	·182
2·40	56	7	·178
2·41	55	30·5	182
2·42	54	·4	·183
2·43	53	·6	·180
2·44	52	·2	·186
2·45	51	29·8	·193
2·46	50	·6	·197
2·48	48	28·0	·222
2·49	47	27·7	·227
2·50	46	·5	·236
2·51	45	·6	·229
2·52	44	28·2	·220
2·54	42	·0	·222
2·55	41	27·8	·226
2·56	40	·9	·224
2·57	39	·6	·229
2·58	38	·9	·224
2·59	37	·7	·227
3·00	36	·8	·226
3·01	35	·5	·231
3·02	34	·1	·237
3·03	33	·2	·236

Time of day	Time.	Sc. R.	Temp.
3·04	32	·4	·232
3·05	31	·3	·234
3·06	30	·8	·226
3·07	29	28·0	·222
3·08	28	·4	·216
3·10	26	·3	·218
3·11	25	29·0	·206
3·12	24	28·8	·210
3·13	23	·5	·215
3·14	22	·9	·208
3·15	21	·9	·208
3·16	20	·9	·208
3·18	18	29·3	·201
3·19	17	30·2	·187
3·20	16	·2	·187
3·21	15	29·8	·193
3·22	14	31·2	·170
3·23	13	·1	·172
3·24	12	·0	·173
3·26	10	·5	·165
3·27	9	32·0	·157
3·28	8	·0	·157
3·30	6	31·7	·162
3·31	5	32·4	·150
3·32	4	33·0	·140
3·33	3	32·8	·143
3·34	2	33·0	·140
3·35	1	33·5	·131
3·35·5	0·5	34·0	·123
3·36	0	....	·107

March 30, 1910.—Height of water, 37 feet 9 inches. Clear during the night; overcast during the morning; clear towards noon; overcast during the afternoon and evening, with fresh N.E. wind. Air temp.: max., 38°, min., 34° F.

The *Lady Grey* left dock at 6.30 a.m., and proceeded up the lake to the head of the cut, slicing away the ice along the channel wherever possible. The ice was very rotten. The cut was continued for a distance of 3½ miles. Considerable quantities of conglomerate frazil ice were met with along this cut; this ice was still fairly firm, and was by no means as badly honeycombed as the uniform ice elsewhere. This is due to the fact that the axes of greatest conduction are pointing in all directions, and besides layers of frozen snow, &c., prevent the conduction of heat from the water and air into the ice. Beyond this frazil accumulation the clear ice was very rotten. The *Lady Grey* cut through 2,000 feet of this ice without stopping. The *Lady Grey* anchored about 3 p.m., but owing to a slight break in the engine room was obliged to return to Three Rivers with one engine. The *Lady Grey* docked about 5.10 p.m.

Conglomerate ice lasts longer than conduction surface ice.

Clear ice very rotten.

Water temperatures:—

7 a.m.—Sc.R. 39·3 T = + ·037 between Three Rivers and Port St. Francis.
2.30 p.m.— 35·0 + ·107 in channel.

March 31, 1910.—Overcast during the night, with heavy rain; overcast during the morning; weather clears towards noon, and remains fine and clear. Air temp.: max., 48°, min., 34°.

Lake ice moving out.

The *Lady Grey* left dock at 9.30 a.m. On arriving at Port St. Francis it was noticed that the whole body of lake ice was moving

down. The *Montcalm* and the *Lady Grey* spent the entire day in patrolling the foot of the lake, cutting up the ice as it came down and in dislodging the ice when it stopped or showed signs of slowing up. The boats returned to dock about 6 p.m.

Water temperatures:—

10 a.m.—Sc.R. 35 T = + ·107° C.

April 1, 1910.—Fine and clear during the night; fine and clear during the day. Air temp.: max., 43°, min., 32° F.

The *Lady Grey*, after taking on coal, left Three Rivers about 9 a.m. During the morning ice had been moving out of the lake. About 10 a.m. the whole field was stuck along the channel near No. 8 lightship. Both the *Montcalm* and the *Lady Grey* set to work to cut a channel through this field. The ice started to move about 2 p.m., and the two boats retreated to the foot of the lake, where they kept cutting through the ice as it came down, and so enabling it to pass easily through Port St. Francis. The two boats returned to Three Rivers about 5.30 p.m.

Ships break up a jam of ice at the foot of lake.

Water temperatures:—

9 a.m.—Sc.R. 29·0 T = + ·206 near Port St. Francis.
9.20 a.m.—Sc.R. 29·0.

The water temperature is here rising owing to breaking up of the ice and exposure of surface.

Open water produces higher temperature.

April 2, 1910.—Fine and clear during the night; same during the forenoon; partly cloudy during the afternoon and evening. Air temp.: max., 47°, min., 36° F.

The *Lady Grey* left Three Rivers about 6 a.m. On arriving in the lake it was found to be clear of ice, with the exception of the north side of the channel. Along the Point du Lac channel the ice on the south side had shoved and piled up over the ice on the north side, with the result that large masses of ice were stranded on the bottom in 15 to 18 feet of water. These 'shoves' were as much as 15 feet high. These had the effect of anchoring the ice on the north side. During the forenoon the *Lady Grey* ran up and down the channel at full speed close to the edge of the ice in order to break up the ice by means of the ship's swell. At 12.30 a.m. it was decided to proceed up to Sorel; the loose ice met with on the way was very rotten owing to the high temperature of the water. Opposite the lights on Stone island a very heavy piece of 'batture' was found barring the way. This ice was about 4 feet thick and packed with frazil underneath. Above this barrier the ice extended about three-quarters of a mile. This batture proved to be the hardest ice to cut of any met with during the winter. As soon as this mass, which was only about 100 yards wide, had been cut through, the ice above easily gave way before the ship, and open water was met with at the head of Boat island. The *Lady Grey* arrived in Sorel at 4.35 p.m.

Stranded masses of ice left in the lake.

"Lady Grey" starts for Sorel.

Bad jam at Stone Island.

Arrival at Sorel

Water temperatures:—

1 p.m.—Opp. Port St. Francis—Sc.R. 17·3 T = + ·397° C. Ice extending for 2 miles up stream. Lake open above.
1.55 p.m.—In channel along Point du Lac Range—Sc.R. 17·5 T = + ·394° C.
3.15 p.m.—In ship channel below Stone Island—T. ° = 0·60° C. Ice jammed opposite Sorel.
4.30 p.m.—In channel opposite Sorel—Temp. with Mercury Thermometer, 34·3 F. T. = +1·3° C.

Readings show influence of warm Richelieu water on river temperature.

"Débâcle."

It will be understood from these values to what extent the weakening of the river ice in the spring is due to a very small increase in the temperature of the water. The 'débâcle' begins on the land. The sun's heat melts the snow, with the result that heated water drains into the small brooks, &c., where this heat is absorbed, melting away the ice. As soon as the ice has disappeared in these small tributaries the larger creeks and streams are the next to feel the effect of the warmed water, whose heat is absorbed in clearing them of ice. This is the order along which the process goes on, and evidently the last ice to go is that in the main waterway. This accounts for the rule stated by the river pilots and captains, that the Lake St. Peter ice begins to move a stated number of days after the Richelieu is free of ice. This means that the Richelieu, once clear of ice, is able to supply heat at a definite rate to the colder St. Lawrence. Since there is approximately the same quantity of ice to be melted every year before the lake ice becomes weak enough to start, the process will require an interval of time, which is not very different year by year.

Effect of the Richelieu on the St. Lawrence.

April 3, 1910.—Fine and clear during the night, with fresh wind; fine and clear during the day.

The *Lady Grey* left Sorel for Montreal at 5.30 a.m. The whole river was practically free from ice; here and there large piles of ice on the banks showed where a 'shove' had taken place. The *Lady Grey* arrived in Montreal at 9 a.m., the first steamer of the season to come up the St. Lawrence to Montreal.

"Lady Grey" arrives in Montreal.

Montcalm arrived in Montreal on April 3 also.

SECTION II.

Measurement of water temperatures by means of a new marine Thermometer.

One of the most important developments resulting from the study of ice conditions under the assistance of the department, has been the perfection of a new type of marine thermometer, which was specially designed for obtaining small variations in water temperature from the ship going at full speed.

In 1896, I first drew attention to the important influence which the minute variations of water temperature had on the formation and disintegration of ice. An electrical thermometer of special design was employed at that time, but this instrument proved to be much too delicate for work on board ship.

After several trials and failures, an instrument was evolved which has proved to be very satisfactory for our work. Our thermometer, a description of which follows, was arranged to be supported over the side of the ship about five feet under the surface of the water. Wires led from this instrument to the chart room, where a simple wire bridge and Weston portable galvanometer made it possible for us to accurately record temperatures to 1/1000 of a degree centigrade. This could be done while the ship steamed at full speed, with the greatest ease. This gave us a measure of the average temperature of the water over a wide area, a measurement of great importance, as we shall show in a later work.

Hitherto marine temperatures have been made entirely by the 'drop bucket' method at stated intervals. This gives, however, by no means an accurate idea of the true water temperature. The influence of local surface currents are completely averaged out by the electrical method, and much new and useful information could be obtained by a temperature survey of the ocean with this instrument. The thermometer is of the electrical resistance type, in which the variations of the resistance of a metal wire serve to give a measure of the changes of temperature of the medium in which the instrument is immersed.

The resistance of the wire is made so high that small variations in temperature produce comparatively large increments of resistance. The problem of suitably arranging the measuring instruments and galvanometer is a mathematical one, to be worked out for each particular resistance.

It was decided to make the coil of 125 ohms, consisting of 250 feet of pure iron wire wilk, covered and wound on a copper cylinder about four inches in diameter and six inches wide. This cylinder fitted accurately inside a second copper cylinder. The ends of the cylinders were carefully soldered and rendered water-tight, while the connecting wires passed out through the middle of the outer cylinder. A stout copper tube was riveted on to the outer cylinder, to which other copper tubes could be fastened. The wires passed through a lead cable to the chart house, where they were connected to the bridge for obtaining a measure of the thermometer resistance. Thus the absolute temperature as well as the small variations could be accurately measured. More recent development has shown that it is possible to record automatically the temperature to 1/100 of a degree by means of a suitable modification and combination of a Calendar recorder and our wire bridge. Although these additions were not made in time to include in our ice studies, they are at the time of writing being employed in an investigation of the influence of icebergs on the temperature of the sea water now being carried out by the kind permission of the department on the trip of the C.G.S. *Stanley* to Hudson straits. I shall have the honour of presenting a report of this work at a later date. Much valuable information was made possible with the use of this instrument. Readings could be taken as often as every half minute, and hence curves could be plotted showing the variations of water temperatures. So sensitive was this thermometer to the changes in temperature of the water, that the influence of the sun shining for one minute on the open water was easily measured. A temperature gradient of 1/10 of one degree per mile was accurately recorded as the ship steamed at half speed from open water up towards an ice field.

The final form of concentric ring thermometer was not obtained without many trials and alterations before the best form was devised.

Many discouragements and failures through faulty insulations were overcome, but it may be said that the final form is free from fault in that it is of great strength combined with the maximum sensitiveness necessary.

I am deeply indebted to the department for the necessary assistance in perfecting this instrument, which I hope may be of practical assistance in marine work. Other forms may be devised for permanently fastening on the side of a ship, but a description of these must be reserved until later.

SECTION III.

Effect of the sun on general ice conditions. Absorption of the sun's heat in the water.

It is evident from Mr. King's report on the ice conditions throughout the winter, and more especially in the spring, that the sun is the chief factor in rotting the newly-formed ice and preventing the formation of ice in open water.

It has been known for a long time to power-house operators using water, that no bad effects from frazil or anchor ice are ever noticed when the sun is shining. Even though a 'shut down' has occurred, as a rule, a few hours of sunshine the next day relieves the situation. Not until the present work was completed did I fully realize the great influence of the sun as a means for reducing the formation of ice.

As soon as the whole body of water is brought to the freezing point in the autumn the formation of surface ice proceeds at a rapid rate at all points where the current is not flowing too swiftly for ripples and eddies to form. Once the surface has solidified the wind has no further influence on it. Coarse-grained ice such as is usually formed at first, and especially ice on the surface on which snow has accumulated, scatters the sun's heat and prevents its absorption by the water. Thus the surface ice becomes a means of keeping the water at the freezing point during the winter and long into the spring, when the ice is disintegrated by the sun's heat. Without the surface ice the sun's heat is absorbed practically completely, and the temperature is elevated sufficiently above the freezing point to prevent the formation of ice.

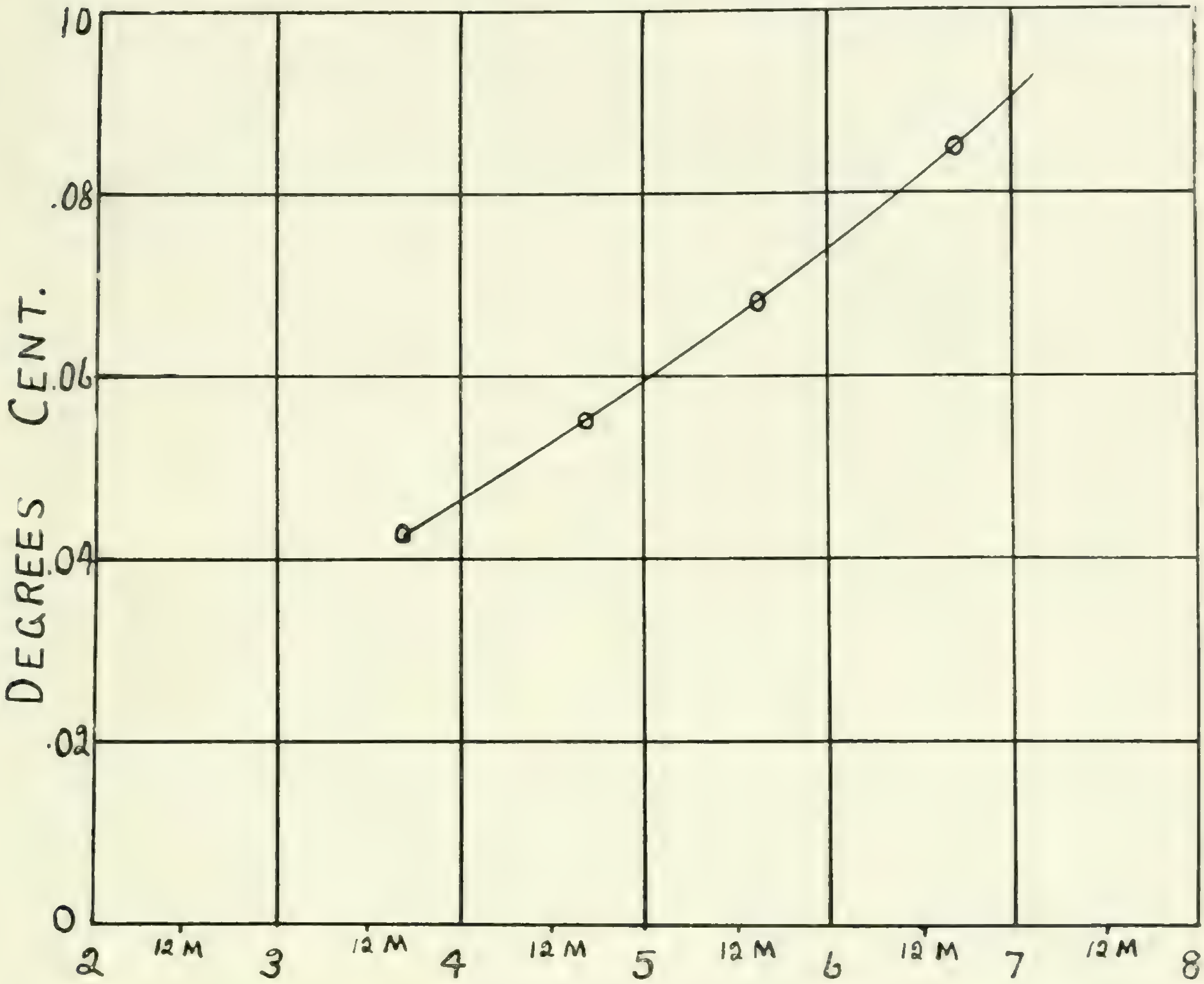
Surface ice can form only at such times when the air is below the freezing point, the wind is not blowing and the current is not sufficiently rapid to produce eddies. The problem of preventing surface ice from forming is not so difficult when these various factors are taken into account. The problem of artificial wave production is one which we are considering as a practical means of preventing surface ice.

The effect of keeping the river open at Cap Rouge was felt all the way up to Three Rivers. This was mostly due to the free rise and fall of the tide not being interfered with by the ice bridge. The open water also served as a great absorption chamber for the sun's heat. Our water temperature measurements in the channel at Quebec were surprisingly high, and had a great influence in weakening the ice. The effect of several days of bright sunshine during the early part of March is shown in the accompanying curve.

Some important preliminary conclusions were arrived at by Mr. King from a study of the curves taken at Three Rivers of the absorption of the sun's heat in the open water. These curves were repeated several times, and by the kind courtesy of the department the measurements were continued at Crane island during the latter part of the month of April.

The curve shown on page 29, taken from the observations made on March 27 from the deck of the *Lady Grey* at anchor, shows the remarkable accuracy with which small measurements can be obtained.

FIGURE NO. 4.



March, 1910. Rise of water temperature.

The diurnal variation is represented not by a single sine harmonic curve, but more accurately by a quasi-periodic function of the type,—

$$\theta - \theta_0 = \mathrm{A}e^{\alpha t} + \beta \left\{ \operatorname{Sin} \frac{2\pi}{\mathrm{T}} (t + \mathrm{E}) - \operatorname{Sin} \frac{2\pi}{\mathrm{T}} \mathrm{E} \right\}$$

where θ is temperature at time t,

θ_0 is the temperature at noon (t = O).

T is the length of a day (24 hours).

e is the base of naperian logarithms.

A is a constant.

α, β, E, are constants which can be expressed in terms of the solar and radiation constants, sun's declination, latitude, &c.

In the curves shown on p. 29, the heavy one represents the result of the observations, the dotted curve the theoretical curve of the

type shown. The observations are shown by the small circles, and it will be seen that the fluctuations are only a few thousandths of a degree, the whole range in temperature is only 0·15° C. On April 13 another similar curve was obtained with a range of only 9/100 of a degree.

A remarkable result was shown by the high value of the solar constant, even though the sky was clouded. The clouds act as a blanket in cutting down the radiation constant from the earth.

An interesting feature of the Crane island work was the difference in the character of the rise of temperature in the water below and above 4° C., the point of maximum density. As soon as the water was warmed by the sun it sank, giving rise to a fairly uniform temperature throughout the water. As soon as the 4° was passed the warm water tended to remain on top, thereby giving greater extremes of temperature at the surface. I have shown elsewhere that nearly the whole of the solar heat is absorbed in the first five feet of water. The action of the sun in dislodging anchor ice makes it appear probable that some heat may penetrate as far as 30 feet below the surface in a comparatitvely clear river water.

It was interesting to observe the effect of scattered clouds on the temperature of the open river. Thus temperature streaks were observed in the water during such times, denoting the effect of a strong sun contrasted with the weaker radiation through the clouds.

In the accompanying curve, No. 5, is shown the result of the Crane island observations, and illustrates the way in which the water of the river rises in temperature. With the ship at anchor the current was sufficient to give a fairly accurate integration of the temperature, similar to the ship in motion in quiet water. There appears to be some source of radiant heat other than the direct rays of the sun. This is probably a scattering effect from the upper layers of the atmosphere before the sun actually rises.

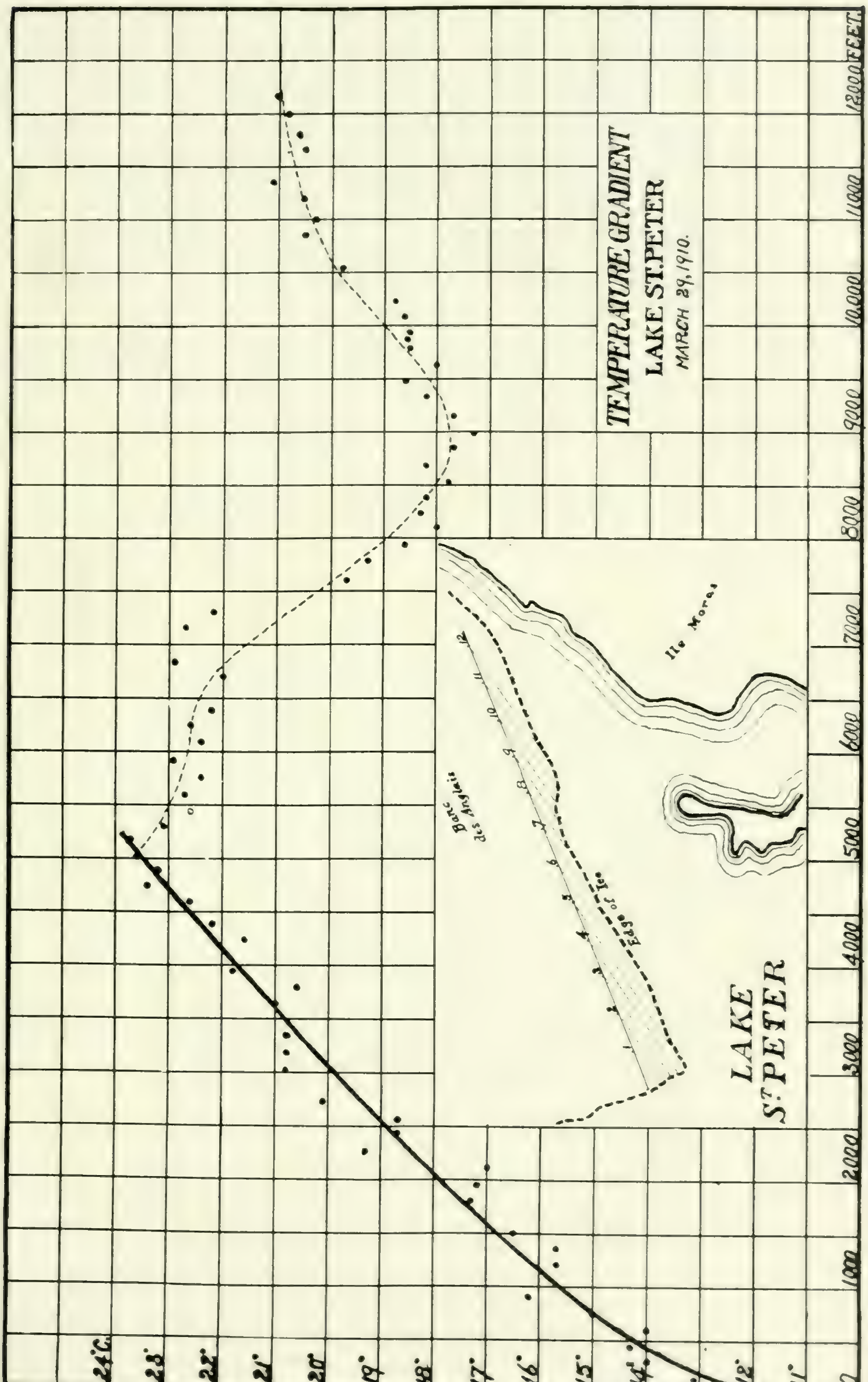
SECTION IV.

Influence of Ice on the Temperature of Water.

Some observations were made by Mr. King, and detailed under date of March 29, pages 31 and 32 in this report, which in a remarkable way illustrate the effect of ice in lowering the temperature of the water.

From anchor at Port Francis the ship steamed at half speed up towards the field of ice on Lake St. Peter, from which the water was running. The accompanying diagram (fig. 6) illustrates the results of the observations. The map included in the diagram shows the direction of the ship, marked off in thousand feet intervals. The set of the current is shown by the dotted lines and the edge of the ice field is shown by heavy dotted lines. The curve is seen to fall at first, indicating the nearer approach to the ice, then rise again as the distance between the ice field and the ship becomes greater (measured along the direction of the current); from a distance of one mile the temperature drops at the rate of 1/10 of a degree per mile until within 500 feet, when it drops more rapidly. These results suggest a possible

FIGURE No. 6.


TEMPERATURE GRADIENT
LAKE ST. PETER
MARCH 29, 1910.
LAKE ST. PETER
Banc des Anglais
Edge of Ice
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11000
12000 FEET.
11°
12°
14°
15°
16°
17°
18°
19°
20°
21°
22°
23°
24°C.

means of telling the proximity of large masses of ice in the open water of the sea. Otto Pettersson has shown in his study of the influence of icebergs on ocean currents, that a large mass of ice acts thermodynamically as a great source of energy. Thus he finds that there are three currents set up by an iceberg in melting. A fresh water cold current which rises and flows out on all sides from the berg, an under-current of cold saline water which sinks, and a middle warmer current which sets in towards the berg and melts it away around its central portion. It is a matter of interest to see how far away it is possible to tell the presence of the berg by a delicate thermometer. The importance of this work has been recognized by the department, who at the time of writing has allowed Mr. King to make some observations from the C.G.S. *Stanley* during her trip to Hudson straits.

Other facts make it appear probable that delicate recording thermometers would be of use to a ship navigating the ice track. Thus the temperature of the Arctic current is influenced by the proximity of masses of ice, and it is hoped that some useful information may be obtained from observations now being made by Mr. King.

August 6.—At the time of revising this report word has been received from Mr. King that interesting results are being obtained.

SECTION V.

On the Rate of Growth of Surface Ice.

The rate at which ice will grow on the surface of a lake or river and the thickness it will attain during any particular season, is a matter of considerable interest. There has been very little, if any, scientific work done in this direction, and the data available are practically useless for determining more than approximately what the growth will be in any particular case. The meteorological conditions are so varied that this complicates the question. The opportunity to study the natural growth of ice is not often at hand with suitable conditions for obtaining measurements. A favourable chance came only once during Mr. King's stay on the *Lady Grey*, and the result of his measurements is recorded in this report, on page 16. Nevertheless it has been possible to obtain much valuable information from a study of these measurements. At my request, Mr. King has spent a great deal of time analysing these results, and while we feel that more extended measurements are required to verify and support the various points raised, yet the matter is of so much interest and importance that I venture to give some account of it here. It is not possible in this report to give an adequate description of the mathematical analysis necessary to arrive at the various conclusions, but I reproduce here the main points, leaving to some future time the full discussion in order that more extended observations may be made. The main factor in ice formation is the loss of heat due to conduction through the ice into the air, but the growth of ice will be affected by loss or gain of heat due to convection currents in the water. There will be a cooling effect due to evaporation from the surface of the ice, which will be governed by the relative humidity of the atmosphere and by the velocity of air currents over the surface of the ice.

There will also be a loss or gain of heat due to radiation. This will include the effect of radiation to the ice from the atmosphere, and the reverse effect of radiation from the ice. The effect of conduction is the largest, and the others may be considered small in comparison. It makes the problem simpler to consider the equations for the first and largest conditions, and then see what effect each one of the others has on it, rather than try to deduce an expression involving them all, which would prove to be too complicated. In the first case, that of ice losing heat by conduction, we consider a slab of ice kept at the freezing point on one side and losing heat to the air on the other. The boundary condition between the ice and air is specified by Newton's law of cooling, which states that at the boundary the rate of loss of heat is proportional to the difference of temperature between the surface of the conductor and the air temperature. The conditions must be in this case still air saturated with moisture.

Under these simple conditions, an expression of the form—

$$\frac{K}{\rho L}\int^{t}\theta dt = x\left(l_0 + \frac{x}{2}\right)$$

can readily be obtained where—

K = conductivity of ice.
ρ = density of ice.
L = latent heat of fusion of ice.
θ = temperature of air.
x = distance the ice has attained at a time t.
l_0 = an expression whose physical interpretation is that of distance.

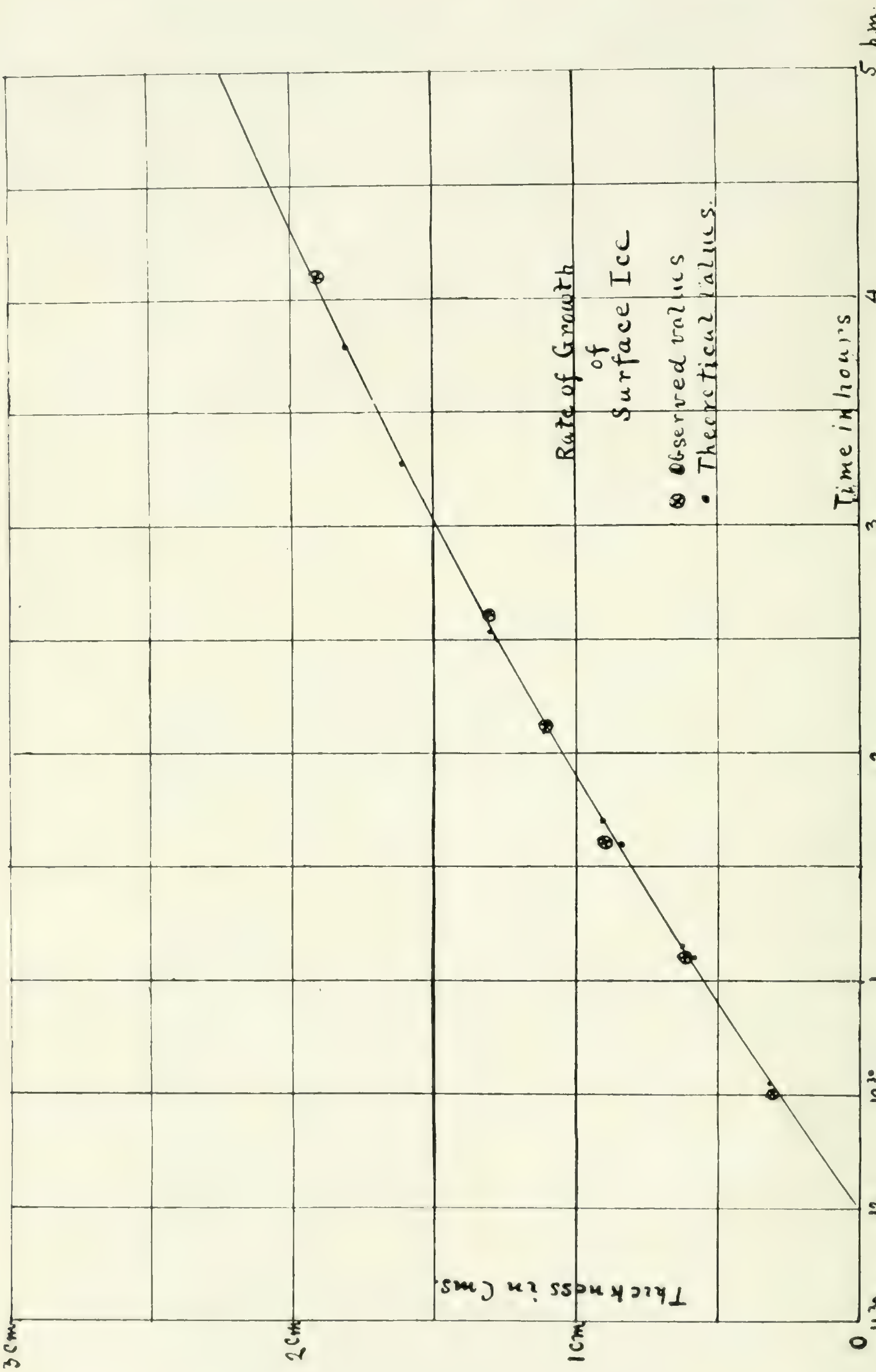
Thus if heat flows from a conducting slab to a bad conducting material at temperature of $-\theta°$, the result is the same as though the thickness of the conductor were increased by an amount l_0 and the surface kept at the temperature $-\theta°$. In order to determine l_0 it is necessary to take a series of observations on the rate of growth of an ice sheet.

EFFECT OF CONVECTION ON THE RESULT.

Precise measurements to 1/1000 of a degree have shown variations of the order of 1/100 of a degree about zero in the temperature of the St. Lawrence river during winter. Sometimes this is above and sometimes below the freezing point. If the water under the ice is in motion, as is usually the case in the St. Lawrence, then convection currents play an important part in adding to or melting the underside of the ice. Usually the water under the ice is slightly warmer than the freezing point, and hence the introduction of a term in the equation may be shown to indicate that a limiting thickness exists to which ice will grow, which may be deduced if we examine an experimental curve such as Mr. King obtained, and a theoretical expression for the rate of growth deduced from the consideration of the effect of conduction alone.

This idea of a limiting thickness is a very important one, and Mr. King has shown that the limits depend on the mean air temperature over a given period and the mean water temperature measured from the freezing point in 1/1000 of a degree. Thus it is possible to arrange in the form of a diagram a simple means for finding the

FIGURE No. 7.


Rate of Growth
of
Surface Ice
⊗ Observed values
• Theoretical values
Time in hours
Thickness in Cms.
3 Cm
2 Cm
1 Cm
0
11 30
12
12 30
1
2
3
4
5 p.m.

limiting thickness to which ice will grow having given these two conditions. The condition of 'no-ice' may exist, and these limits are quite readily obtained from the diagram. The appearance of open holes in a lake or river otherwise frozen over thus becomes easily explained. Some point such as a shoal where the warmer under water is deflected up to the surface, or where a warm spring of water rises from the bottom of a lake. Measurements recorded from the *Lady Grey* show a decidedly higher temperature in one air hole in Lake St. Peter (page 24).

ATMOSPHERIC HUMIDITY.

The effect of evaporation from the surface of the ice is one which has been hitherto almost entirely overlooked. The effect was noticed last year on the ice breaking operations of the *Montcalm*, and mentioned in my report. The same effect was observed this year on more than one occasion, as is mentoned in section I.

The effect of humidity on the growth of surface ice is surprisingly great in the initial stages, but as we might surmise, becomes smaller as the ice grows in thickness. On dry days surface ice forms much more readily than on damp days with no evaporation.

It is possible to arrive at some important conclusions in considering the effect of humidity on the rate of growth of ice. The temperature at the surface of ice is higher than the air temperature, especially when the ice is thin. The relative humidity of the air at the surface of the ice will be diminished, that is evaporation will take place with greater rapidity, so that the cooling effect will be greater than the depression of the wet and dry bulb hygrometer. This is supported by the fact that dense clouds of hoar frost emanate from the surface of open water and thin ice in cold weather (θ below 10° F.). The air in contact with the water and thin ice is warmed to some extent, and so is able to take up more water vapour than it can contain when it is carried by convection into the colder portions of the atmosphere. Thus even when the relative humidity of the air is 100 per cent evaporation may still go on over water and over ice which is thin enough to transmit sufficient heat and sensibly warm the air in immediate contact with it.

Since the latent heat of evaporation is very large, the effect is very great in the early stages of ice formation, increasing the growth at least 50 per cent up to nearly one inch in thickness. (See fig. 8.)

EFFECT OF RADIATION.

The layer of ice is capable of losing or gaining heat from the atmosphere by direct radiation. Owing to lack of experimental data on the diathermancy of ice and how the transmission is affected by its thickness, it is difficult to estimate the effect on ice formation arising from this cause, but it is probably small. It would seem that ice would be transparent to the radiation from water at zero. If, therefore, the radiation term is independent, or almost so, of the thickness of the ice, the effect may be included with that due to convection. The term will depend on the state of the sky, the amount of sunlight and the condition of the surface of the ice as regards an opaque layer of snow. The accompanying diagrams illustrate the conclusions arrived at from our study of ice conditions:—

Curves—Experimental curve (fig. 7).
Effect of humidity (fig. 8).
Limiting thickness (figs. 9, 10 and 11).

Figure No. 8.

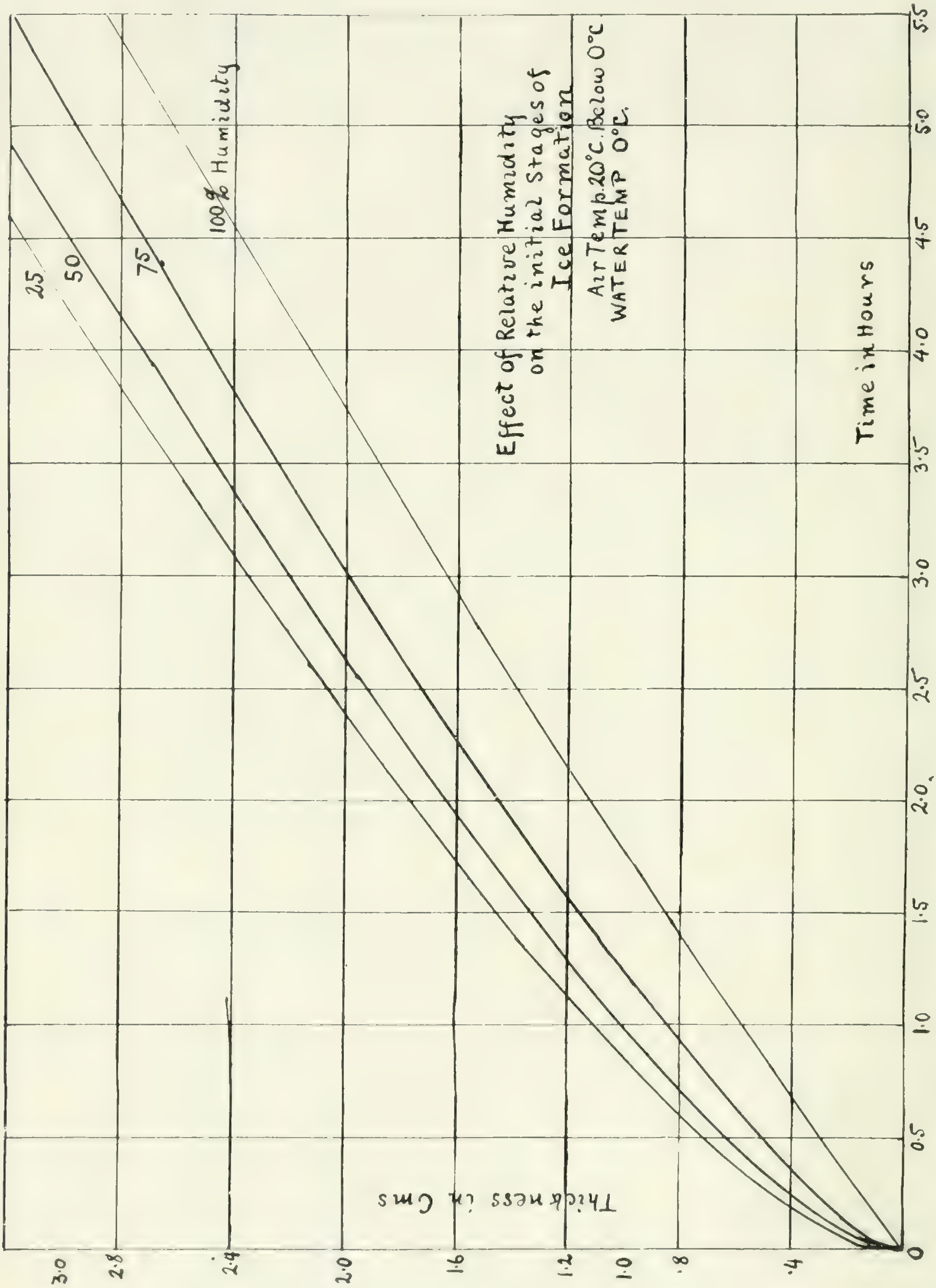

Effect of Relative Humidity
on the initial Stages of
Ice Formation
Air Temp. 20°C. Below 0°C
WATER TEMP 0°C.
100% Humidity
75
50
25
Time in Hours
Thickness in Cms
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
·4
·8
1·0
1·2
1·6
2·0
2·4
2·8
3·0

FIGURE No. 9.

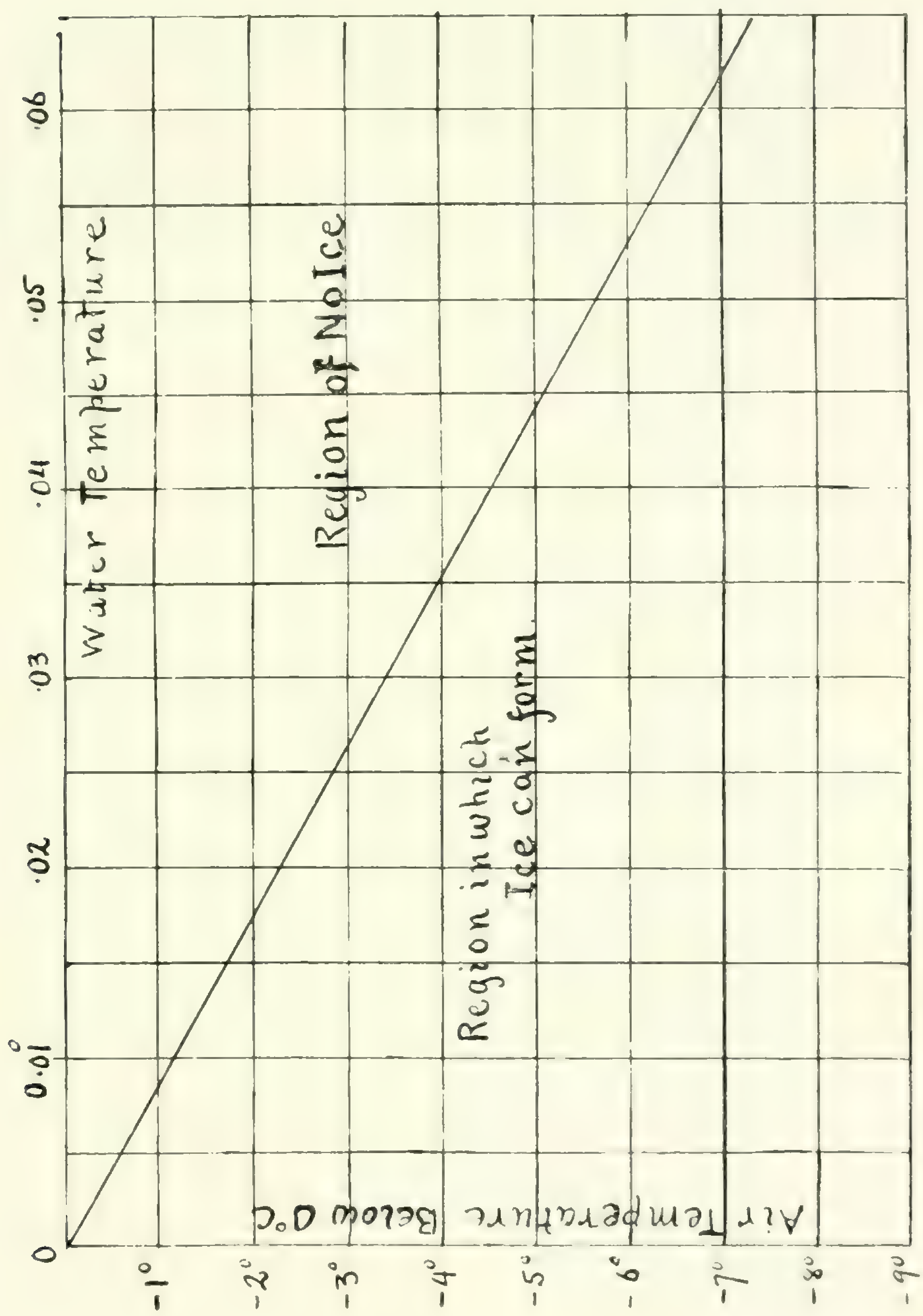
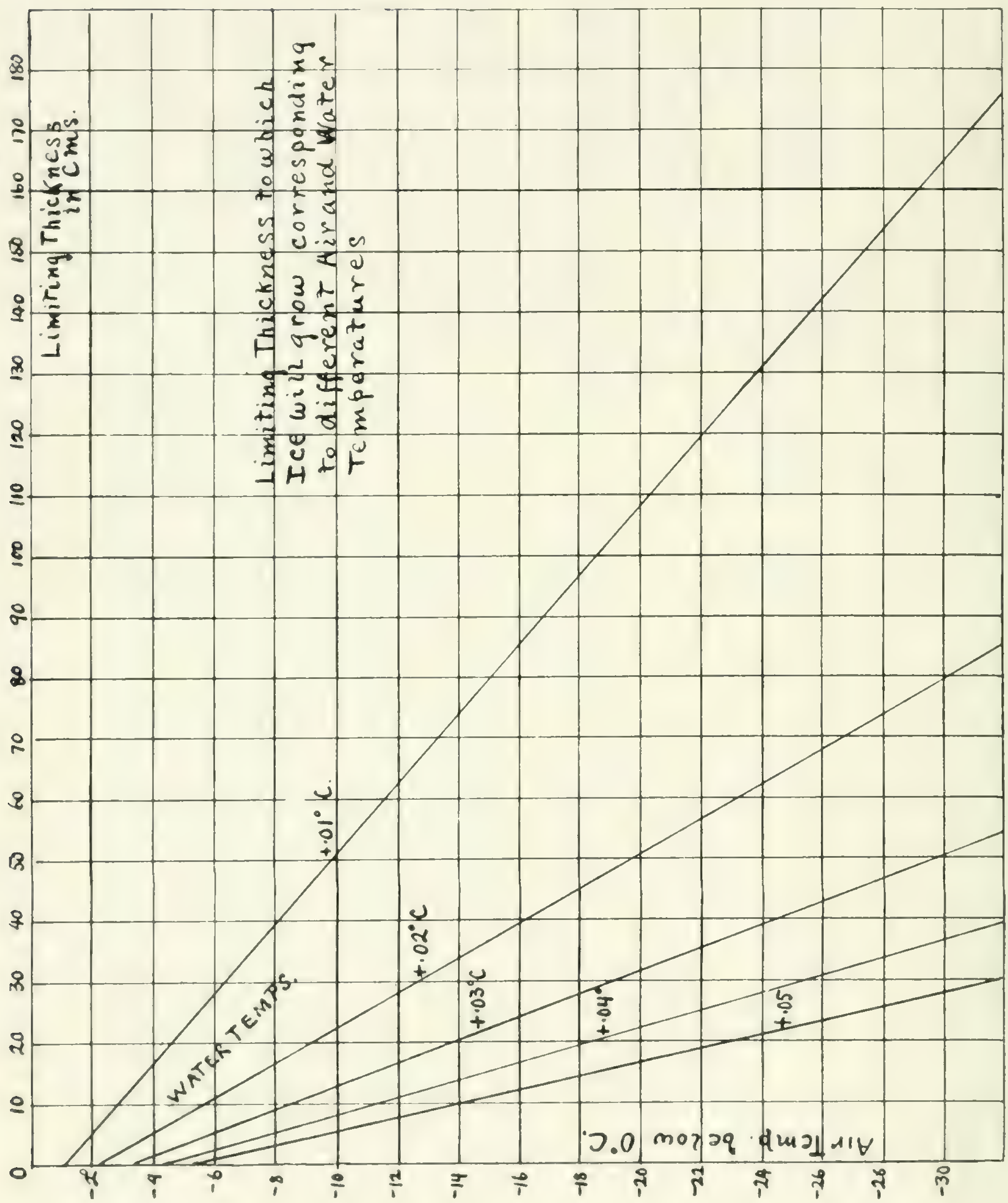

Water Temperature
Region of No Ice
Region in which Ice can form
Air Temperature Below 0°C
0
0.01°
·02
·03
·04
·05
·06
-1°
-2°
-3°
-4°
-5°
-6°
-7°
-8°
-9°

FIGURE No. 10.


Limiting Thickness in Cms.
Limiting Thickness to which Ice will grow corresponding to different Air and Water Temperatures
Air Temp. below 0°C.
WATER TEMPS.
+·01° C.
+·02° C
+·03°C
+·04°
+·05
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30

SECTION VI.

Some problems affecting the maintenance of an open channel between Montreal and Quebec during the winter.

While my work has been primarily to gather information of scientific value in connection with ice formation, I could not help devoting much study and thought to the question of an open channel through the river and possible winter navigation of the St. Lawrence. With the growth of the volume of trade and the opening up of the west, the needs of a winter port at Montreal will be greatly felt.

While I believe the use of ice breakers at suitable points would undoubtedly be effective in clearing the channel of ice throughout the winter, I do not think the river as it is at present would be commercially navigable under such circumstances. The danger to ships would be too great from inshore ice and snowstorms to make it possible to take the risk. Quite apart from this, however, incalculable good would result from the clear channel. Floods would be avoided, and the season of navigation would be substantially increased, at both ends.

It must not be understood that I regard winter navigation as impossible. On the contrary, I believe that a moderate expenditure of money in various parts of the river would so alter the conditions as to vastly improve the channel in summer and render the course safe and secure in winter. I believe this so firmly, that I have no hesitation in predicting that Montreal will be a yearly port just as soon as the commercial interests demand it. The problem will not be found to be so difficult or so expensive as it is at present believed.

I am not basing my conclusions alone on my many years' study of the ice conditions in the river, for as early as 1886 the Royal Commission appointed to study the St. Lawrence river, with a view to finding some remedy for the winter and spring floods, issued a very elaborate and valuable report, giving a careful ice survey of the river above and below Montreal. The result of their study showed that the floods were occasioned by the winter packing of the ice, and that all this could be avoided by keeping the channel open to tide water. The St. Lawrence is not subject to floods such as affect many of the American rivers; its flow is more uniform. The winter and spring floods are entirely due to ice jams. Floods may last for a few hours, or a week or more. The one of 1858 lasted two weeks. There are certain critical spots in the river, where the ice forms first which starts the pack. Thus, at Lake St. Peter the ice bridge causes the water to rise behind it. The winter level of Lake St. Peter itself is four or five feet higher than the summer level, while the river below is open, but when that is closed it rises seven or eight feet.

Mr. T. C. Keefer, C.M.G., one of the greatest authorities on the ice conditions of the St. Lawrence, describes, in his Presidential Address before Section Three of the Royal Society of Canada, the taking of the ice over the St. Lawrence in 1886, when he studied the question as a member of the Flood Commission. That year, the ice bridge took at Nicolet, the lower end of Lake St. Peter, on December 4, and the lake was covered to Stone island, 20 miles above, in 30 hours. The ice then reached Sorel, seven miles further on, in 14

hours after. It reached Vercheres, 23 miles above, in 78 hours. After five days thaw, it reached Verennes, going nine miles in seven days. The upward march to Longue Point (seven miles) was made in two days of cold weather. The whole of the river channel for 55 miles above Lake St. Peter to Lachine rapids was covered in about three weeks.

At the St. Mary's current, ice shoves are most frequent. Sometimes the water rises as rapidly as a foot in less than two minutes. During the great flood of 1886, the water in Montreal harbour rose 27 feet above the summer level, by an ice jam below Hochelaga. This gave way suddenly, before the pressure caused by this head, and the ice-laden wave (starting at 27 feet) was precipitated down the river. It dropped in amplitude only three feet in the first mile, and was 20 feet at Longue Point, which elevation it maintained for a distance of 30 miles. It finally reached Sorel with a height of 16 feet above summer level, in 10 hours, going at the rate of 4½ miles per hour. Undoubtedly this is one of the greatest bores on record.

The Flood Commissioners, after very careful deliberation, came to the conclusion that winter navigation was perfectly feasible, and that there would be a great deal to be gained by keeping the St. Lawrence clear of ice, from Montreal to tide water, in order to give a free passage for the ice. They recommended the use of breakers, and a boom to be built across the base of Lake St. Louis, to keep back the lake ice. Ice-breaking tugs for the harbour of Montreal were authorized in 1885, but were never put in operation. Experiments on explosives to break up the ice jams were tried, but were found to be of little use in the masses of packed ice. Moreover, they were very expensive, quite apart from any value in moving the jams. Recent experiments in Russia have given the same result.

They stated that the prevention of the ice bridge at Lake St. Peter would result in an open channel up to the Lachine rapids. The current under a head of one and one-fifth of an inch per mile, was found to be effective in other parts of the river in keeping the surface clear of ice. As it is now, the ice bridge at the lake stops the floating ice, and pack rapidly runs back, covering the entire river. All this ice would pass out to tide water if the ship channel through Lake St. Peter and the Sorel islands were kept open.

Strong winds might at times hold back the broken ice, but an ice breaker would have to operate whenever possible, and the current in the lake of one mile per hour would soon empty out the broken pieces.

In the spring, instead of thick, hard, clear ice on the lake, which is difficult to break and retards the opening of the river above that point, we should find a surface of water practically free of ice. No floods would result, and the ships could begin running to the port of Montreal early in April, if not in March.

It is very likely that the open lake would to a large extent react on the lower parts of the river, and make the problem at Cap Rouge much easier. A walled channel through the lake, as is built through Lake St. Clair, would, of course, solve all the difficulty in connection with that immense area of ice which forms there and which must pass out before navigation can open in the spring. This canal, or series of piers, would outline the channel, and probably possess sufficient current to prevent freezing. The ice on the rest of the lake would be

held in and allowed to disintegrate in the spring without moving down to block the channel. The canal thus formed would help to maintain an open channel throughout the rest of the river. On the other hand, the ice on the lake might be allowed to freeze over and a channel through it cut out later. The current through this would probably keep it clear of ice for the rest of the season. It might, at first sight, be thought that the boats employed in the lake to keep the ice broken up would become frozen in and helpless. Such boats could be supplied with pipes in order to blow steam into the water around them. The effect of such a small amount of heat in this way would effectually prevent a boat freezing in. The effect of a ship like the *Lady Grey* in warming the water immediately surrounding it, is very great, as I have previously shown (page 19). We always noticed that even in the coldest weather a ship like the *Lady Grey* never freezes in, but the ice is loose and disintegrated all round the ship from the natural heat of the ship and the effect of the circulating water. This could be increased very much by the use of special steam ejectors for the water. A case has been recorded where a pond in which a dredge was working was kept open for a month with the air temperature at 30 below zero Fahrenheit, by blowing steam from an old 60 horse-power boiler, burning waste stumps, into the water under the dredge. At the end of this time, the operations were stopped only by the inability to work the machinery of the dredge in the intense cold. Under normal conditions, the pond would freeze solid to the bottom. This is but one example of many which could be cited to show the wonderful effect of a small amount of heat in preventing ice formation. A thin surface layer a few hundredths of a degree above the freezing point will effectually protect the water from ice.

The hardest work of the ice breaker is in December and January, which may be termed the two 'ice months.' In February the sun becomes stronger and assists very much the work of clearance. In March, practically no new ice is formed of any size.

In Russia, winter navigation has been found to be commercially feasible, and many ports of the Kara sea require ice breakers in summer to reach northern Siberia.

Captain C. H. Webb, R.N.R., who for three years was navigating officer on the waters of Vladivostock, informs me that in the worst weather, ships are escorted to their berths by the ice breakers, where they are allowed to freeze in until they are ready to sail, when the ice breaker brings them out again. It frequently happens that a ship will freeze in so securely during a single night as to enable them to discharge their cargo the next morning on the ice. In the face of all these difficulties (but they are real difficulties) it is found to be commercially feasible to navigate in the coldest weather.

Thus, it appears from previous study of the river that there are three points where efforts would have to be made to prevent prolonged stoppages of ice. Cap Rouge, which has been successfully handled this year; Nicolet, at the base of Lake St. Peter, and at the Sorel islands. With Lake St. Peter free of ice, we may safely predict an open channel above that point. The river is continually struggling to free itself of its icy burden, and every attempt to assist at vital points will be found to be far more effective than we can, at the present time, sufficiently appreciate.

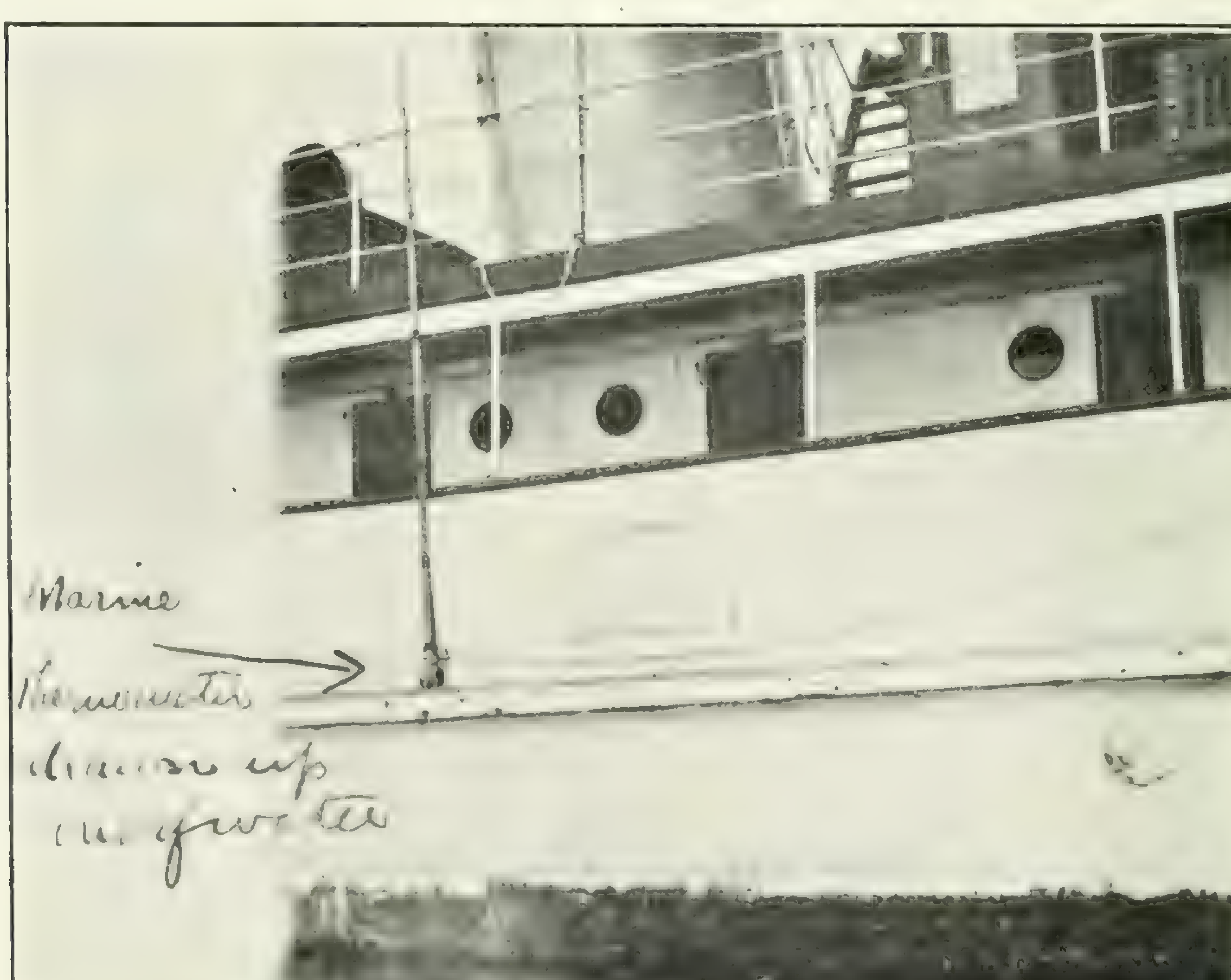
THE INFLUENCE OF ICEBERGS ON THE TEMPERATURE OF THE SEA.

By H. T. BARNES, D.Sc., F.R.S.C.,
Macdonald Professor of Physics and Director of the Physical Laboratories;

and LOUIS V. KING, B.A.,
Lecturer in Physics, McGill University.

The development of a new recording thermometer for the precise measurement of water temperatures has been made possible through the generous aid of the Department of Marine and Fisheries. The character of the work which this instrument is capable of doing has been already described in a previous report to the department, where it was shown that temperature measurements to a thousandth part of a degree enabled the presence of ice to be detected in the open water of the river for a long distance.

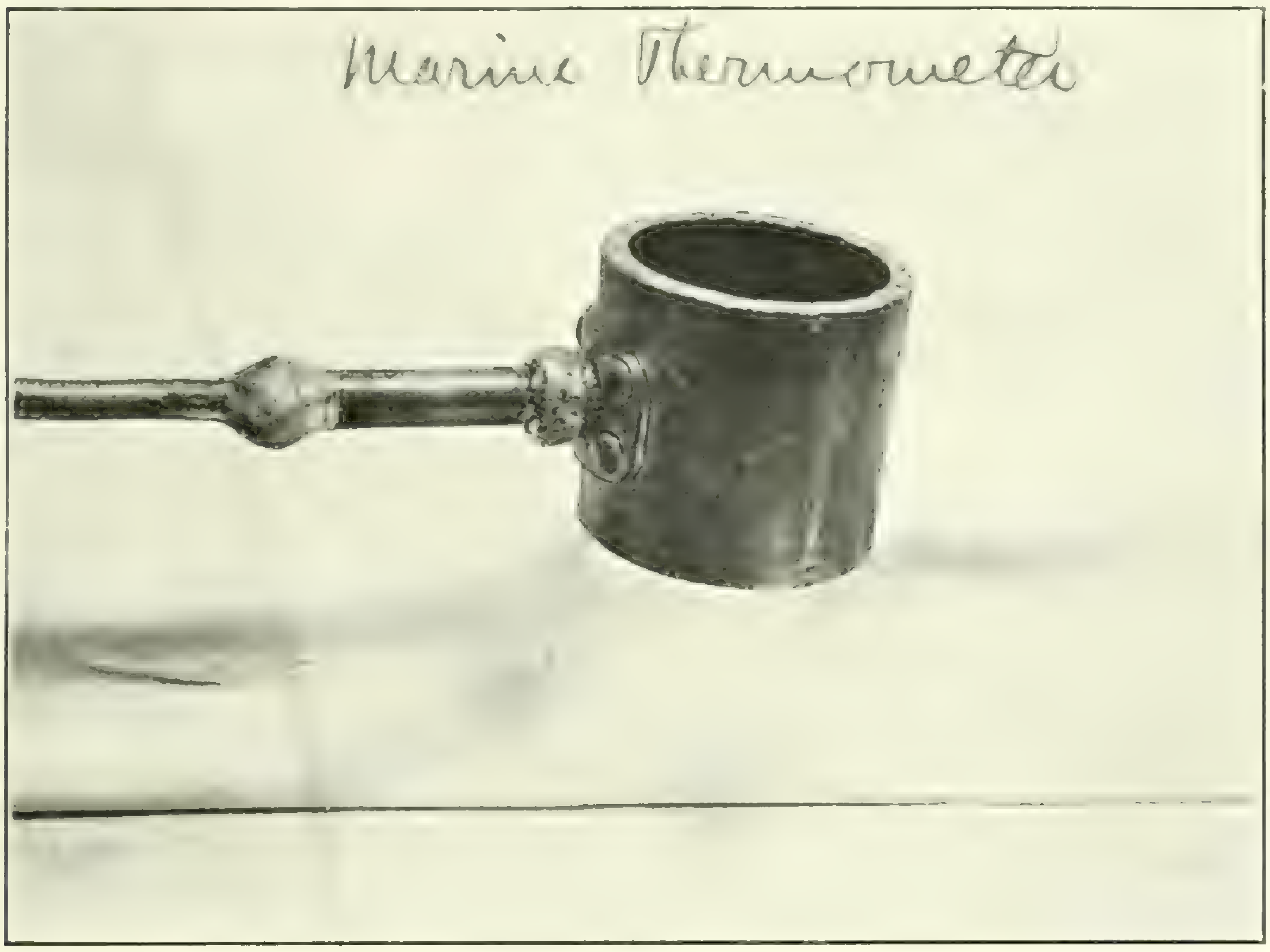
Application was made to the department for assistance to study the influence of icebergs on the temperature of the sea, and through the kindness of the minister, Hon. L. P. Brodeur, and the deputy minister, Mr. G. J. Desbarats, passage was obtained for one of us to proceed to Hudson's straits on the C.G.S. *Stanley*, which sailed for those waters on July 2. The installation of instruments consisted of



Marine Thermometer drawn up out of water.

two marine micro-thermometers of the anchor-ring type, one being the same as employed during the winter at Cap Rouge, and later at Crane island, and briefly described in the report on Ice Formation on

the St. Lawrence. The other was one of a pair made similar to it and of somwhat improved design. The thermometer was carefully fixed over the side of the ship, and trailed through the water at a depth of five feet below the surface. The wires passed through a lead covering inclosed in copper tubes, which helped to hold the thermometer rigid. The lead cable was passed through flexible iron pipes where it left the copper pipe near the deck of the ship, and was taken direct to the observer's cabin. In the cabin the wire bridge was placed where measurements could be made of the sea temperature to one-onethousandth of a degree, on a scale equivalent to two feet of



Marine Thermometer.

wire to one degree of temperature. Resistance boxes, accurately calibrated, enabled temperatures to be read to the desired accuracy at any point on the scale. Hence at the boundary of currents when a comparatively large change of temperature occurred, the reading could be quickly brought on the scale and the exact temperature estimated.

In order to have the readings continuously recorded, it was found possible to adapt a Callendar recording mechanism, with special Weston relay. A switch enabled the thermometer to be connected to the recorder, and traces obtained on a scale represented by eight inches to one degree. The sensitiveness of the arrangement enabled the records to be accurately obtained to one-onehundredth of a degree.

The value of this arrangement can be appreciated when it is stated that records could be obtained with the thermometer continuously in the water and the ship going at full speed. So successful did this prove, that the heavy seas encountered outside the Straits of Belle Isle, along the Labrador coast, produced no effect whatever on the working of the arrangement. It was found that the exposure of the bulb of the thermometer by the waves produced no irregularities, in as much as the air in direct contact with the sea did not differ from the water to any amount that could be observed. On the deck

of the ship a Stevenson screen was placed, which had been kindly lent by Mr. R. F. Stupart, Director of the Meteorological Service. In the screen was placed a Friez recording thermograph and a hygrograph.

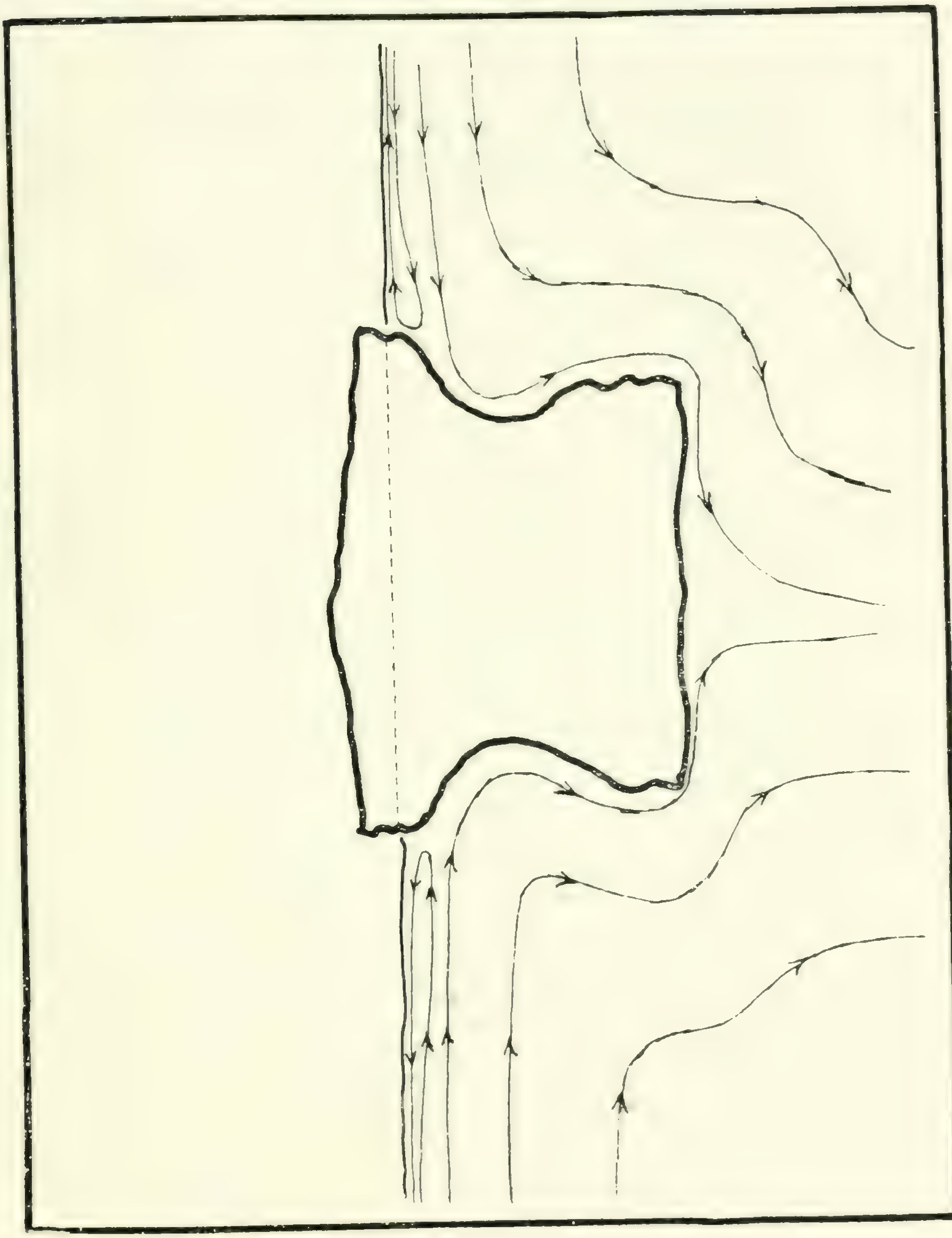
IMPORTANCE OF CONTINUOUS RECORDS FOR STUDYING SEA TEMPERATURES.

As a matter of seaboard routine, sea temperatures are taken frequently, every half or quarter of an hour. The opinion of navigators seems to be divided as to the value of these observations. For instance, Captain Lecky, in his 'Wrinkles on Navigation,' quotes Lord Kelvin as saying, 'The conducting power of water is so small that there would be absolutely no cooling effect by conduction to a to a distance from an iceberg, but there might be a considerable effect by the cold and light fresh water running down the iceberg and spreading far and wide over the surface of the sea.' This contention of Lord Kelvin's is supported by the work of Dr. Otto Pettersson, who shows *experimentally* that in the neighbourhood of ice melting in *salt* water, 'we can discern three different currents: one on the surface which flows from the ice; another current at intermediate depths which runs straight towards the ice; while a third current, consisting of water cooled by contact with the ice, sinks to lower depths.'

The disposition of these currents is sketched in fig. 12, adapted from a drawing in Dr. Pettersson's paper.[1] When the melting by air proceeds faster than the melting by water the iceberg will rise; the portion hollowed out by the action of the water-current setting towards the berg will rise above the water line, and the mass of ice will present the curious mushroom-like forms often observed in a field of heavy sea ice (eight feet or more thick) during the final stages of melting. On the other hand, Lecky quotes the opinion of captains of north Atlantic lines as being extremely variable. On some occasions the bridge thermometer will give an indication which turns out to be justified, while on other occasions the near presence of an iceberg seems to leave the instrument unaffected. It must be remembered, however, that data have up to the present time been obtained by means of the ordinary 'drop bucket' method, including a mercury or alcohol ship thermometer which has little to recommend it as regards sensitiveness. The instrument is not, as a rule, graduated to read more than a single degree, which represents an interval on the stem of only one-eighth of an inch. On the scale of the electrical thermometer mentioned a single degree of temperature is represented by an interval of *two feet*, so that variations which would be absolutely imperceptible to an ordinary thermometer would have an enormous effect on the more sensitive instrument. Besides, the usual method of taking observations leaves considerable room for uncertainty,—a sample of water is taken on board in a bucket, the thermometer is immersed and the temperature read off. Granting that the temperature has been noted correctly, there is nothing to guard against the sample having been taken in a place of merely local fluctuation. (We have actually observed a quartermaster take a thermometer out of the water to take a reading, and have heard of cases where the bulb was held in the hand while the temperature was

[1] 'The Influence of Ice Melting on Oceanic Circulation.' Geographical Journal, vol. 30, p. 295 (1904).

FIGURE No. 12.



Ice melting in salt water—from experiments by Dr. Otto Pettersson.

being noted.) As against this, the marine thermometer described is towed alongside the ship, and thus averages up the temperature along its path. Owing to a slight lag in the instrument small scale fluctuations are not recorded. Then again temperatures taken as often as four times an hour in a ship going at eight knots only gives temperatures every two miles. The temperature of the sea oscillates, independently of ice, slowly from time to time, so that comparisons made between observations taken at intervals of even a mile apart are of absolutely no value in determining whether icebergs affect the temperature of the sea or not. This explains, perhaps, the conflicting experiences of north Atlantic sea captains already mentioned.

It will be obvious from the preceding remarks that an extremely sensitive continuously-recording instrument is needed for the work described, and that the presence of an iceberg will make itself felt by the persistence of a gradient of temperature. The persistence of a drop of temperature can easily be noticed on a continuous record, while discrete observation might miss it entirely.

MEASUREMENTS AND CURVES MADE DURING THE TRIP.

Although it was impossible to delay the ship on the way up in order to make a special study of icebergs, the thermometer was installed and the recorder set going on July 8, shortly after leaving Sydney, N.S. Everything was found to work satisfactorily, and a number of thermographs were obtained during that day. On July 9 the ship proceeded through a heavy fog. The thermometer at once indicated the passage of the ship into a branch of the cold Labrador current in the Belle Isle straits by a sudden drop of temperature from 7·2° C. at 5.18 p.m. to 3·7° at 5.35. At that moment a Marconigram was received from the Grenfell Mission ship ss. *Strathcona*, reporting a large iceberg in the middle of the straits. The ship was at this time steaming along very slowly (four or five knots). At 7.52 p.m. a large berg, probably that reported by the *Strathcona*, was sighted just in time to prevent a collision; as it was, the *Stanley* passed within a few hundred feet of it. The portion of the automatic record between 7.30 and 7.43 p.m. is reproduced on the left hand side of chart No. 1, and shows that the influence of the iceberg began to make itself felt about 7.35 p.m., when the temperature read 50° C. Between 7.43 and 7.50 p.m. a new chart was being prepared for the recorder, so that unfortunately the most interesting part of the tracing was not taken. As soon as the ship was reported abreast of the berg at 7.52, direct readings were taken at one minute intervals as the mass of ice was left astern. The following readings were obtained:—

Time.	Temperature.	Time.	Temperature.	Time.	Temperature.
p.m.	° C.	p.m.	° C.	p.m.	° C.
7 11	4·393	8.00	4·214	8.10	4·156
7.52	3·871	8.01	4·198	8.11	4·205
7.54	4·017	8.02	4·245	8.13	4·231
7.55	4·079	8.03	4·235	8.14	4·252
7.56	4·89	8.05	4·205	8.15	4·283
7.58	5·058	8.07	4·130	8.19	4·278
7.59	4·182	8.08	4·121	8.22	4·545

These observations are plotted on the right hand side of the chart, and show how the temperature rises as the distance from the berg becomes greater. It will be seen from this record that going towards the berg there is first a rise of temperature, followed by a sudden drop of at least 1·1° C. in about 12 minutes, i.e., in a distance of a little less than a mile. It will easily be understood from an inspection of this chart how easily the drop in temperature could have been missed by a series of half or quarter hour observations. Unless one observation happened to have been taken about 7.35 and the other about 7.50, nothing unusual would have been observed; for instance, observations at 7.45 and 8 would have shown no difference noticeable on an ordinary ship thermometer. *This bears out the remark already made on the conflicting nature of transatlantic temperature records.*

July 10.—The temperature chart for the day is given (chart No. 2). The day was overcast, with intervals of fog. In the record the temperature is seen to be fairly steady between noon and 9 p.m., i.e., it hardly varies half a degree in a distance of 80 miles. The drop of temperature after that hour was probably due to an approach to the shore. There the colder under currents are turned up to the surface by the gradually shoaling bottom; besides, there are temperature disturbances due to currents of fresh water from streams and rivers along the coast. The latter part of the record was taken while the ship was rolling violently in a heavy sea. This did not in the least affect the working of the recorder.

July 11.—The record for this date is given in chart No. 3, and is interesting because we begin to realize a characteristic feature of the temperature distribution in passing even as far away as one-half mile from a berg.

At 9.20 a.m. a small iceberg, about 70 feet high, was passed at a distance of five-eighths of a mile. Apparently for a berg of this size the ship was just outside the range of the temperature effect, since there seems to be no very marked disturbance in the temperature record at this time.

At 2.21 p.m. the ship passed about one-quarter of a mile from an iceberg. The temperature fell very rapidly to 3·8°, and immediately rose again. On examining the record, a very marked disturbance is noticed about this time. About 1.45 p.m. the temperature rises ½°, and straightway falls through 1·4°, returning almost at once to its original mean temperature.

The ship is recorded as having passed fairly close to a berg about 3.15 p.m.; a disturbance of much the same type can be noticed on the thermograph. About 6 p.m., another berg was passed at a distance of about one-quarter mile. The resulting fall in temperature can be traced on the chart.

The last observation of the day followed shortly afterwards. At 7 p.m. the ship passed within half a mile of a very large iceberg. The temperature first commences to rise at 6.45 p.m., reaching a maximum of 4·6° at 6.50 p.m., and immediately falls with extreme rapidity to about 2·3° at 7.03 p.m., after which it rises rapidly to about 3·6°. As the ship drew away from the iceberg temperatures were taken by direct reading at frequent intervals as follows:—

Time.	Distance from Iceberg.	Temperature.	Time.	Distance from Iceberg.	Temperature.
p.m.	Knots.	° C.	p.m.	Knots.	° C.
6.45	2·8	4·069	7.17	2·6	3·205
7.03	0·7	2·296	7 24	3·6	3·532
7.10	1·6	2·572	7.29	4·4	3·807
7.12	1·9	2·808	7.42	6·3	3·898

As the ship was making about 9 knots an hour, it is an easy matter to draw up a chart showing the variation of temperature with distance. This is done in chart 4. Chart 5 shows the variation of temperature with the radial distance from the iceberg as deduced from chart 4.

Going back to chart 3, the unsteadiness of temperature after 8 p.m. is due to approach to land. The *Stanley* anchored at Tournavik at 9 p.m. The thermometer was hauled on board, and was found to be in perfect condition.

On leaving Tournavik on July 15, charts were taken for a couple of days. The ship did not, however, pass close to any icebergs, and the records possess no unusual features. On July 16 the temperature fell as low as 0·3°, or nearly to 0° C. (32° F.). It is probable that the characteristic rise of temperature would enable the presence of an iceberg to be detected in water reduced to a point so near freezing. About this time occasional small pieces of field ice from Hudson's straits were met with. Since the thermometer was in danger of being carried away by a chance piece of field ice, no readings were taken after this date. Hudson's straits and the bay were found full of large fields of heavy drift ice, both on the way across and on the way back, so that it was impossible to have the thermometer over the side of the ship.

On the return journey preparations were made when still a day's run from Belle Isle, to make a detailed temperature map of the sea near a large iceberg. Although weather conditions were favourable, no icebergs were to be seen either along the Labrador coast or in the Belle Isle straits, with the exception of a small stranded berg near Belle Isle, too close inshore, however, for a near approach.

Temperature readings were taken through the straits; the results are shown graphically on charts 6, 7 and 8. Chart 6 shows how sharply the line of demarcation between currents of different temperatures is shown. By having the recorder set to ship's time any such discontinuity is easily placed on the navigating chart. For instance, from chart 6 the boundary line between the cold Labrador current and the warmer Gulf water is seen to occur about 11 a.m. On referring to the navigating chart (No. 7) this boundary is easily placed geographically.

This presents an interesting feature of the marine thermometer which should be of value in hydrographic work: boundaries of currents and their variations of position with tides, seasons, &c., can easily be worked out from a series of continuous temperature records of the type just described. Chart No. 8 shows a set of direct readings taken every minute to one-onethousandth of a degree during an hour. It shows that the temperature of the sea fluctuates constantly

from place to place within small limits, and verifies the general appearance of the automatic records. These small inequalities of temperature represent thermodynamically a considerable quantity of available energy which in consequence of the poor conductivity of water is not likely to be lost by conduction. This energy is for the most part expended in setting up a small-scale circulation at the surface. It is by this means that the sun's heat is absorbed, and equally distributed throughout a considerable depth of sea. As a result the solar heat absorbed during the day is not given off at night by cooling to the air. The air itself is practically transparent to solar radiation; over the sea we have seen that owing to oceanic convection there can be little partition of energy between the sea and the air. As a result we ought to expect the air temperature to be practically constant during day and night. This is shown by an examination of continuous air temperature records taken throughout the voyage where the diurnal variation of temperature is practically nil. As soon, however, as land is approached the usual diurnal change is observed.

GENERAL CONCLUSIONS.

Although valuable results were obtained on the trip to Hudson straits, when several icebergs were passed, it was impossible to delay the ship for a more detailed study. On the return journey, however, when some time was allowed, no icebergs were met with, and in consequence the results are not as complete as might be desired. However, in the light of preliminary observations the records obtained seem very promising of results which are likely to lead to valuable methods for iceberg detection at sea in time of fog. A careful inspection of the records show that an iceberg affects the temperature of the water in a characteristic way. The temperature first rises rapidly and then falls with great rapidity. This increase in the water temperature is a new and unexpected result and one that demands careful investigation. The explanation is at present not clear. The temperature effect may be due to the temperature reaction at the junction of the fresh surface current from the iceberg mixing with the sea water. It may also be connected with the presence or absence of definite organic life at the junction of the fresh current and salt water. In any case the sharp rise before the fall can be taken to indicate the entrance of a ship into the cold surface current near the berg, and thus gives a preliminary indication of the proximity of ice. Should the rise be followed by a rapid fall below the mean temperature of the water, the presence of ice may be taken as fairly assured.

Thermometers have been designed to fit on the hull of the ship, with the connecting wires passing through the ship's plating. A very promising arrangement for iceberg detection would be to have one of these at the bow, about two feet below the mean water-line, while the other is placed at the stern of the ship as deep down as the draught of the ship will allow, the two thermometers being connected to read differences of temperature. By this means the bow thermometer will catch the cold surface current represented in fig. 12 (only three or four feet deep), while the stern thermometer will remain at the normal sea temperature. In this way whenever the differential record reads so that the bow thermometer is colder than the deep stern instrument, this may be taken as an indication of disturbance due to ice, and

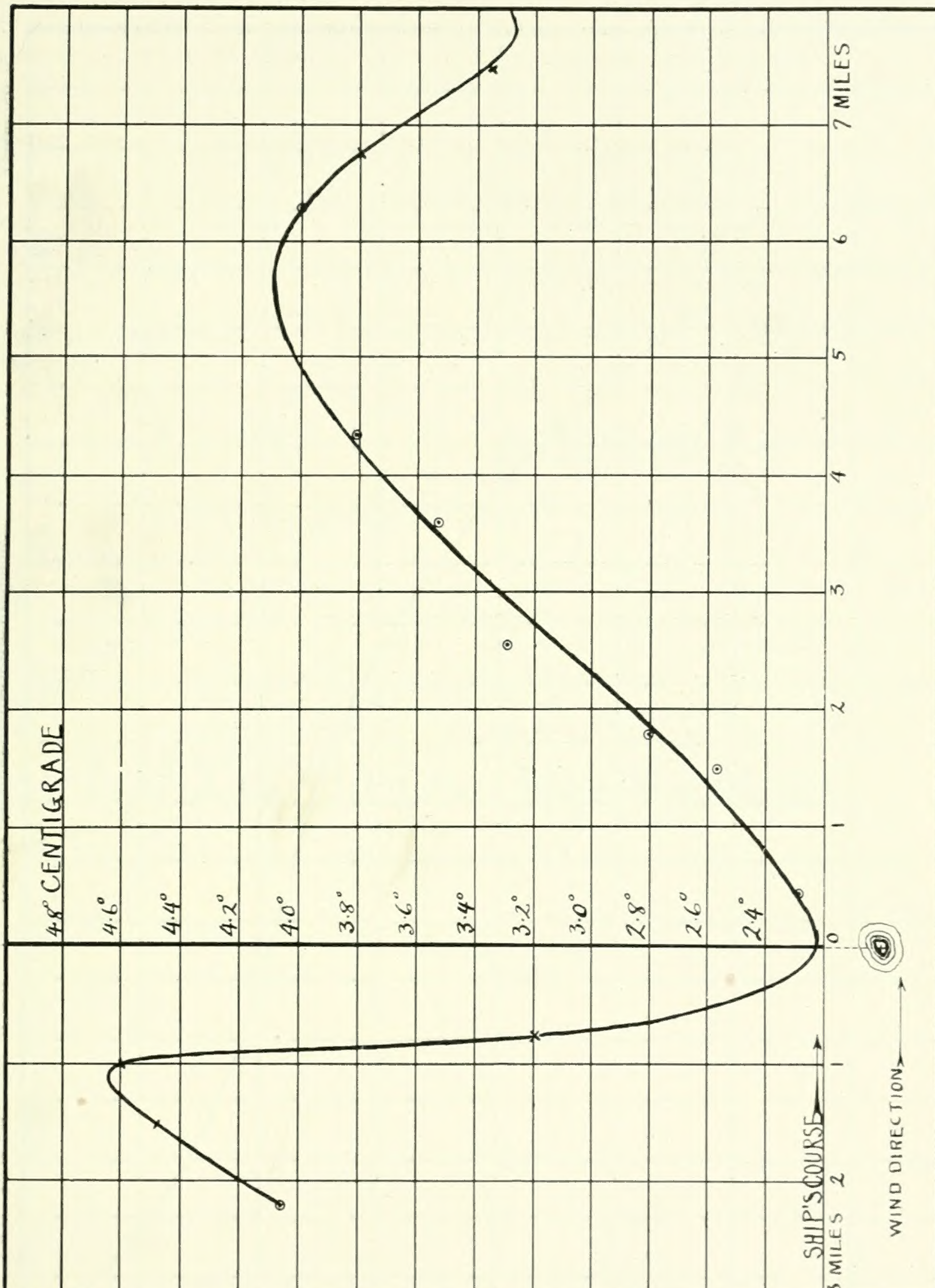
which could be due as far as can be seen to *no other cause.* If this temperature persists and becomes greater, the ship is approaching close to the ice; if it decreases, the ship is leaving the berg behind. Thus in addition to giving a warning of the proximity of ice the instrument would actually be a help towards navigating the ship to safety.

VARIOUS ASPECTS OF AN ACCURATE STUDY OF MARINE TEMPERATURES.

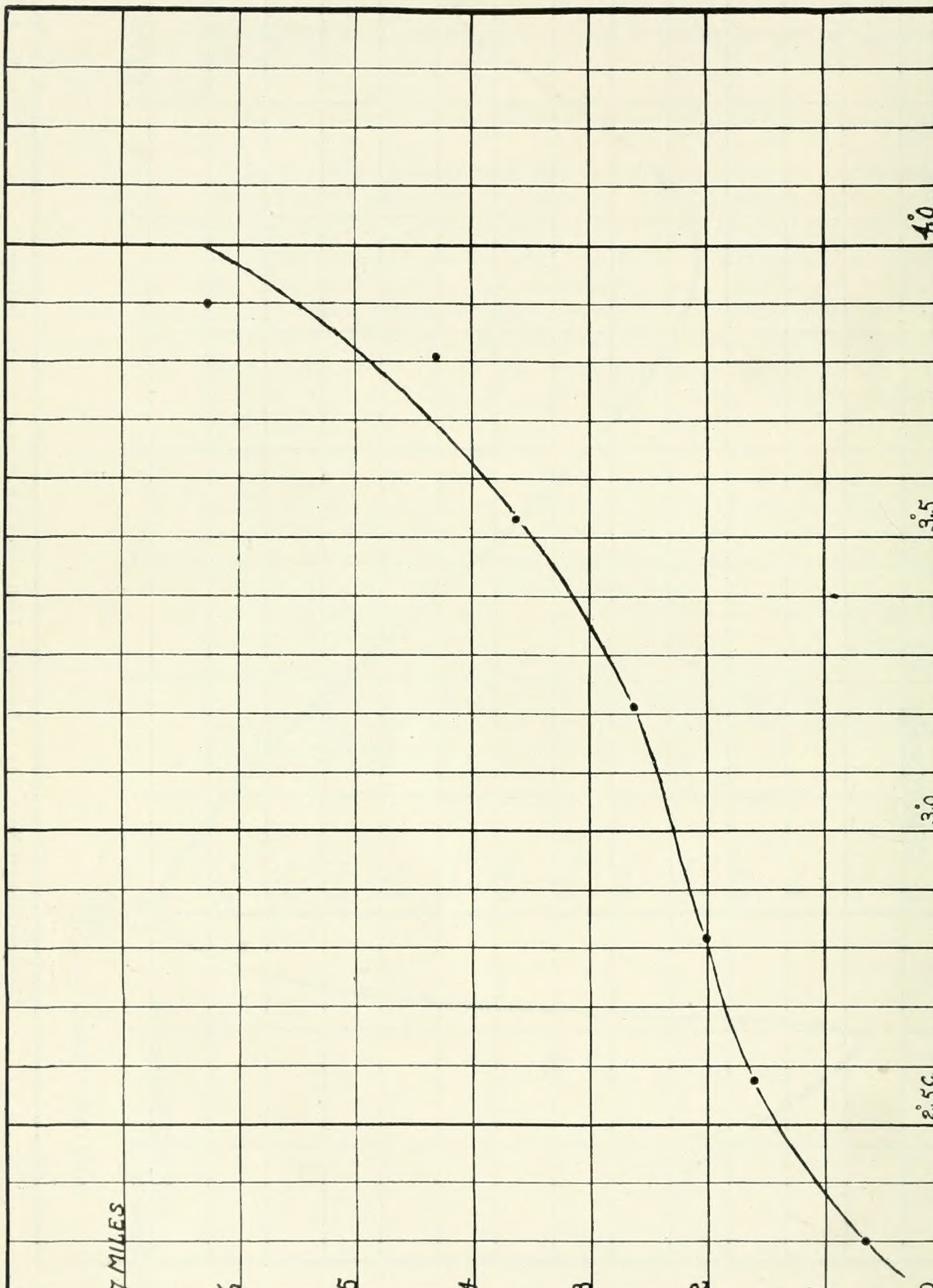
It is a fact already well known that the presence of organic life influences the temperature of the sea. It thus seems highly probable that the small fluctuations noticed over large areas of the sea, such as are clearly brought out in chart 8, are due to the presence of organic life. This is a matter, however, which would require careful investigation. The influence of small changes of temperature on the migration of fish would form an important study that could be well undertaken with the aid of the recording micro-thermometer. What appears to be an important application of the instrument for future investigation would be in accurately locating and tracing the boundaries of oceanic currents.

Besides the disturbing influence of ice on the temperature of the water, which promises to yield a method of solving the iceberg problem for navigation, the influence of shoals and the proximity of land appear to produce disturbances that might serve as warnings to ships running too close to such obstructions.

In conclusion, we wish to point out that further study is necessary in order to obtain more detailed results, and to express our earnest wish that assistance be granted by the department in the use of a special ship for marine temperature work. In making this request, we do so in the full confidence that much valuable scientific and practical information would be obtained.



Temperature gradient near an iceberg. Distances are measured from the iceberg. Chart No. 4.



Radial temperature gradient,

Chart No. 5.